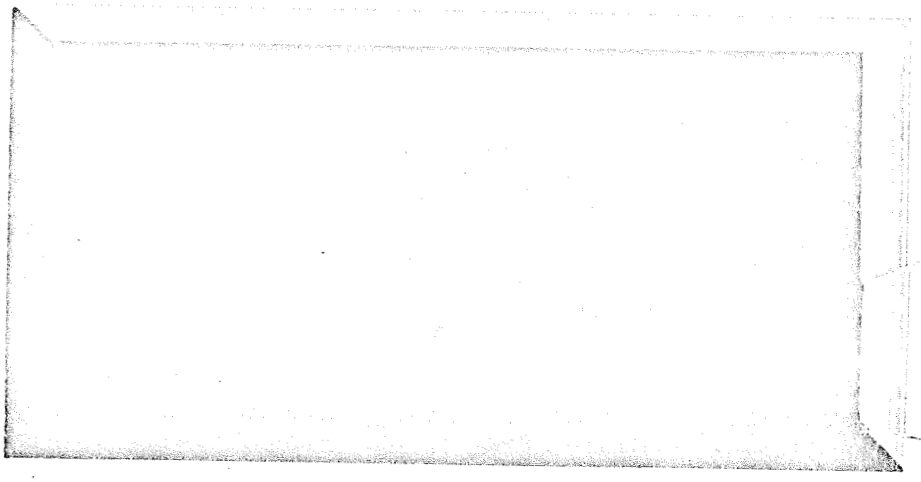

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INTEGRATED MEDICAL AND BEHAVIORAL LABORATORY MEASUREMENT SYSTEM PHASE B II FINAL REPORT VOLUME II - MEASUREMENTS COMPILATION OF STUDY RESULTS

CONTRACT NASW—1630

PREPARED FOR THE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

BY THE

BIOASTRONAUTIC SECTION

SPACE SYSTEMS ORGANIZATION

GENERAL ELECTRIC

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Table of Contents

iii

Table of Contents (Cont)

Pg. 8 BLANK

SECTION 1

SUMMARY

A major task of the Phase B-II has been the revision and refinement of the NASA provided measurement list. In contrast to the detail provided in the physiological and laboratory evaluation area, the direction under the behavioral heading was very general. By means of an analysis, more detailed requirements in these areas were derived for implementation. Most emphasis was placed on the laboratory evaluation because of the complexity of the problem and its influence on the IMB LMS design. Although in Phase B-I, GE recommended preservation and return of all samples, the 1971 proposed flight date and enhanced astronaut training led to a reappraisal.

As the result of the study revision, 165 measurements are proposed for inclusion in IMB LMS (Table 1-1).

Consultants - In the conduct of this study, GE utilized the services of outside consultants in order to provide a broad view and critique of our progress and problems. For example, through Biosystems, Inc., we obtained the services of a variety of specialists, (see Table 1-2) covering all measurement areas.

Supplier Relations - In the course of Phase B-I and B-II, GE has been in contact with over 121 suppliers of equipment and techniques for IMB LMS utilization. For example, in the area of biochemistry, we had profitable exchanges with the following firms:

a. Harleco
b. SKI
c. Dade
d. Ames
e. Hycel
f. Warner-Chilcot
g. Technicon
h. Lab-Line

Table 1-1. Measurement List Comparisons

Number of Measurements Identified on NASA Phase B-II Measurement List		Number of Measurements Recommended for IMBLMS	
Physiological	38	35	(Note 1)
Lab Analysis	66 (Note 2)	106	(Note 3)
Behavioral	8	24	(Note 4)
Totals	112	165	

NOTES:

1. Elastic leotard, central venous pressure, carotid stimulation are not on recommended list.

2. Many represent multiple measurements.

3. Represent individual measurements and procedures.

4. Individual procedures for multiple measurements on NASA list.

Table 1-2. GE Consultants - Biosystems, Inc., Cambridge, Mass.

Consultant	Affiliation	Speciality
Dr. Laurence R. Young	M. I. T. - Department of Aeronautics and Astronautics	Engineering Aspects
Dr. Robert W. Steer, Jr.	Merrimack College	Vestibular and Systems
Dr. Jacob L. Meiry	M. I. T. - Department of Aeronautics and Astronautics	Engineering Aspects
Mr. John Senders	Brandeis University	Behavioral
Dr. Paul Reich	Beth Israel Hospital	Hematology
Dr. Joseph Pines	Beth Israel Hospital	Cardiovascular and Pulmonary
Dr. Murray Golub	Beth Israel Hospital	Chemical
Dr. Lippman Geronimus	Beth Israel Hospital	Bacteriology
Dr. Richard F. Brubaker	Mass. Eye & Ear Infirmary	Cardiovascular and Behavioral
Dr. Ronald A. Laing	University of Massachusetts	Oximetry
Dr. Frank Ervin	Massachusetts General Hospital	Behavioral and Neurological
Dr. John Garcia	Massachusetts General Hospital	Behavioral

1.1 WORKING DOCUMENTS

For each measurement, three documents were provided:

a. Functional flow block diagram

b. Measurement specification

c. Human engineering worksheet

1.1.1 FUNCTION FLOW BLOCK DIAGRAM

Function flow block diagrams were prepared beginning at the system level and extending down to the measurement level. Each measurement was described in terms of the functions to be performed and the derivation of all requirements.

1.1.2 MEASUREMENT SPECIFICATIONS

The measurement specifications include a schematic diagram which shows the stimulus, sensor signal, signal conditioning, computation, control and signal utilization. Other items are the input and output on-board signal characteristics, stimuli and calibration; ground output characteristics; support characteristics and environmental data requirements.

1.1.3 HUMAN ENGINEERING WORKSHEETS

For each measurement, the worksheet includes human engineering design requirements, maintenance, safety, task requirements, displays, control lighting, restraint, work-space factors, time requirements, training requirements, and hazards.

1.2 CREW TIME REQUIREMENTS

From the specifications and worksheets set up, take down and performance times were collated. Totals were corrected for two-man operation, the use of simultaneous measures and for the effect of zero G on performance time. The final value was compared to the crew time available for measurement as derived from the AAP 1-4 time lines.

Although our estimates are preliminary and there remain many uncertainties and assumptions, the crew time requirement for IMB LMS is less than the total available. Major changes in time estimates are expected when vehicle operations times and experimental protocols are established.

1.3 EXPENDABLES AND LOGISTICS

In establishing repetition rates for each measurement and the details of technique and procedures, it was possible to make an initial estimate of the weights and volumes of expendables and biological samples involved. Expendables include sampling and storage containers, analytical supplies, magnetic tape and film. For a 60 day mission, a weight of 98 pounds and a volume of 3.0 cubic feet is required at launch. A weight of 118 pounds and 3.5 cubic feet is required for sample return, including the preservation device.

1.4 PHYSIOLOGICAL MEASUREMENTS

Because these measures are reasonably well defined as compared to the behavioral and laboratory evaluation areas, GE has emphasized hardware implementation and procedures (Table 1-3). Considerations were limited to non-invasive techniques and emphasized safety and ease of use to minimize astronaut training. An example is the recommendation of the ultrasonic Doppler flowmeter which meets these requirements. This device also demonstrates the commonality principle by meeting four measurement requirements.

1.5 BEHAVIORAL MEASUREMENTS

The NASA measurement list contains general behavioral categories. Accordingly, a "tops down-multi thread analysis" consisting of eight phases (see Figure 1-1) was used to identify, trace and substantiate areas of behavioral measurement as a function of:

a. Potential stressors inherent in orbital operations that could reasonably be expected to alter the behavior.

b. The sensitivity or criticality of the behavioral measure selected was of such critical importance that monitoring its status during prolonged orbital flight was required.

Table 1-3. Physiological Measurements

MEASUREMENT	MEASUREMENT RECOMMENDATION	DESCRIPTION	TECHNIQUE
NEUROLOGICAL			
Ref. # (Vol. II)			
3.2.1	Agravic Perception	Study Ability of Orientation	Rod and Sphere (Litter Chair)
3.2.2	Ocular Counter-Rolling	Measure of Otolith Function	Litter Chair (Cinematography)
3.2.3	Oculogyral Illusion	Assessment of Otolith Function	Otolith Goggles (Litter Chair)
3.2.4	Visual Task With Head Rotation	Study of Ability to Perform While Rotating	Litter Chair, Task Elements, (Sequence Camera)
3.2.5	Electronystagmogram	Determination Labrynthine Function	Rotating Litter Chair & Bio Potential Measurement
3.2.6	Angular Acceleration Threshold	Check of Ability to Sense Spatial Illusion	Rotating Litter Chair, Response Key
3.2.7	EEG	Record of General Cortical Activity Levels.	Bio-Potential Sensor
CARDIOVASCULAR			
3.3.1	ECG/VCG	Yields Heart Rate and Electrical Energy of Heart	Graph of Galvanic Impulses Generated by the Heart
3.3.2	Phonocardiogram	Records Heart Valve Function Cycle Timing	Microphone Sount Detection
3.3.3	Cardiac Output	Measurement of Blood Flow and Velocity	Indirect Fick-Method
3.3.4	Arterial Blood Pressure	Assess Blood Pressure	Arterial Cuff (Automatic)
3.3.5	Blood Flow	Assessment of Thoracic, Regional Blood Flow and Arterial Flow Pulse Countour & Reactivity	Doppler Flow Meter
3.3.6	Peripheral Venous Pressure	Determination of Peripheral Venouse Pressure	Peripheral Venous Pressure Gauge
3.3.7	In Flight Exercise	Measurement of Cardiac Stress	Ergometer
3.3.8	Rheology	Evaluated Blood Flow Characteristics	Limb Impedance Measurement
3.3.9	LBNP	Technique Rather Than Measurement	LBNP Cuff
3.3.10	Venous Compliance	Assessment of Tonous of the Venous Bed	Measure Change in Limb Volume with Negative Pressure
3.3.11	Ballistocardiogram	Difficult to Assess Data	6 Degree-of Freedom Ballistocardiography
RESPIRATORY			
3.4.1	Respiratory Rate	Measure of Pulmonary Activity	Thoracic Strain Gauge
3.4.2	Lung Volume	Indication of Lung Capacity	Mass Flowmeter and Integration
3.4.3	Pressure, Flow and Volume	Assessment of Pulmonary Function	Flow Interrupter
3.4.4	Breath by Breath Respiratory Analysis	Determines Oxygen Consumption and Carbon Dioxide Production	Flowmeter Mass Spectrophotometer
3.4.5	Alveolar to Arterial O_2 Gradient	Evaluation of Oxygen Transport Status	Nares Oximetry
3.4.6	O_2 Consumption	Assessment of O_2 Consumption	Closed Circuit O_2 Uptake vs Ergometer Output
3.4.7	Ventilation	Study of Pulmonary Ventilation	Helium Closed Circuit Technique
3.4.8	Diffusion	Used in Determining Cardiac Output	Closed Circuit CO Rebreathing
3.4.9	Arterial O_2 Saturation	Assessment of Oxy-Hemoglobin Status	Nares Oximeter
METABOLISM AND NUTRITION			
3.5.1	Core Temperature	Assessment of Temperature Changes	Ear Thermometry
3.5.2	Body Mass	Determination of Weight Variations	GFE Body Mass Measuring Device
3.5.3	Muscle Size and Strength	Measure of Body Maintenance	Dynamometer, Strain Gauge and Tape Measure
3.5.4	EMG	Evaluation of Muscle Tone	Biopotential Measurement
3.5.5	Energy Metabolism	Determination of General Energy	Derived from Breath by Breath O_2 Consumption CO_2 in Conjunction with Logged Entries of Activity Description and Time.

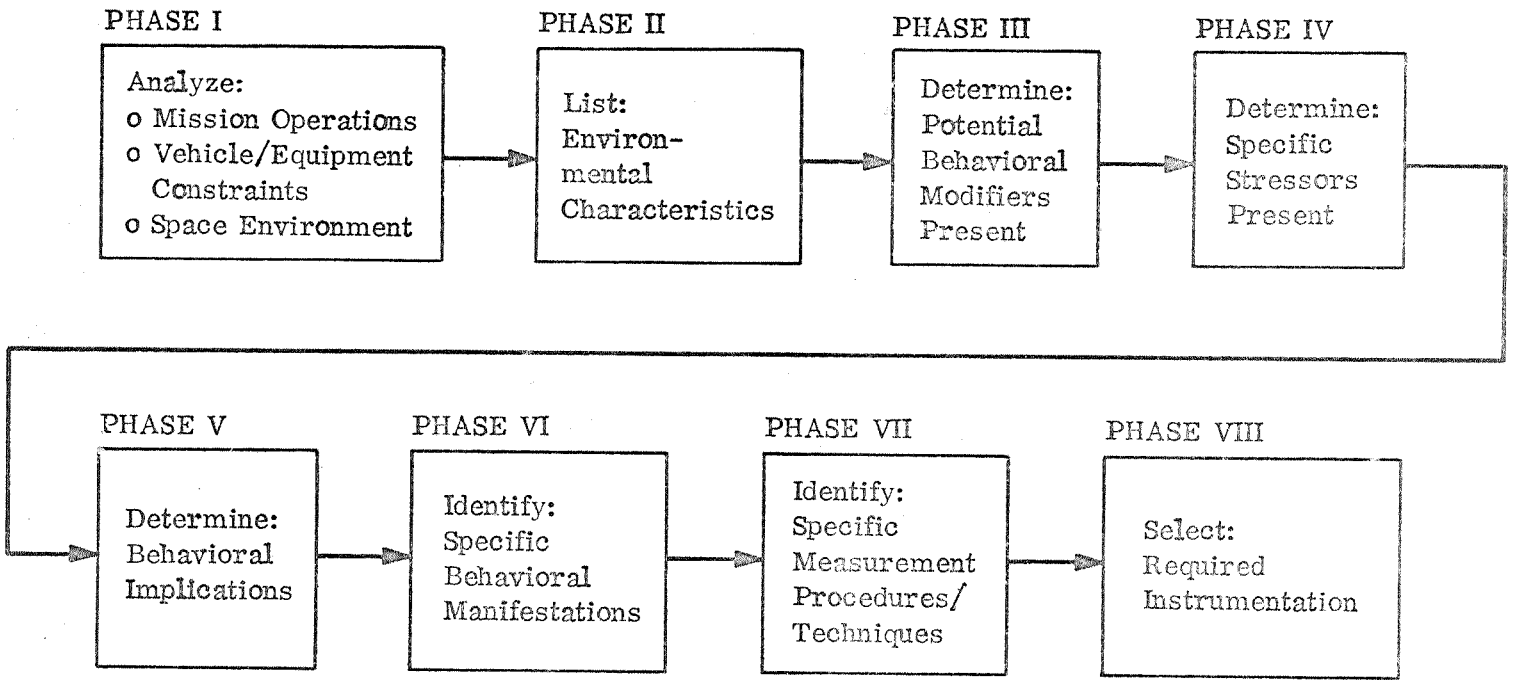


Figure 1-1. Phases of Behavioral Measurements

The list of behavioral characteristics to be measured was analyzed to develop techniques which provided reliable and quantitative data while meeting as closely as possible the constraints imposed by an orbital spacecraft phases of behavioral measurements.

The recommended behavioral measurements are given in Table 1-4.

The measurements have been organized under the generic headings supplied by the NASA to demonstrate the coverage and cross correlation provided by the selected measurements.

Each of the selected measures was described in detail in respect to definition, rationale for inclusion, utility of derived data, and measurement techniques available in IMB LMS. Instrumentation was described wherever capabilities existed. In all cases, the instrumentation chosen was determined as ready for flight qualification by 1971. While several approaches were of high interest, they were not included because of their low probability of availability by 1971.

Consideration has been given in this report to the relationships between physiological and laboratory evaluations and the assessment of behavior. Appropriate combinations of all categories of measurements are an appropriate objective but raised problems with respect to experimental design and crew time allocation.

1.6 LABORATORY EVALUATION

Each measurement on the selected list, as modified by NASA, has been evaluated for possible inclusion in IMB LMS by the following criteria in an on-board vs. post-flight trade-off analysis:

a. Safety

b. Physiological Significance

c. Complexity

Table 1.4 Recommended Behavorial Measurements

Behavioral Parameters

1. Arousal Levels
2. Psychomotor Function
3. Shifts in Circadian Cycles
4. Physical adapt. to Wt. Lessness
5. Personality Stability
6. Emotional Stability
7. Vestibular Mechanism Function
8. Kinesthetic Function
9. Anxiety levels
10. Inter-personal relationships
11. Memory
12. Sensory Functions
13. Cognitive Functions
14. Time and Motion
15. Mission Directed Activation

Distribution of Parameters (NASA Areas of Measurements)

Sensory Test Battery

Visual (12)
Auditory (12)
Cutaneous (12)
Kinocthetic (8, 12)
Clinical Evaluation

Clinical Evaluation

Crew Intercommunication
(1, 3, 4, 6, 9, 10, 13, 15)

Learned Behavior

Reaction Time (2, 3, 4, 6, 9, 12, 14, 15)
Tracking (2, 12, 13, 15)

Vigilance (1, 3, 6, 9, 11, 12, 13, 14, 15)

Memory (1, 3, 6, 9, 11, 13, 15)

Higher Thought Process (1, 3, 5, 6, 9, 11, 13, 14, 15)

Partial List of Measurement Techniques

Test Technique	Instrumentation Area Behavioral Barometer
Mass Discrimination Test Kit	Behavioral - 1, 2, 4, 8, 12, 13, 14
On board communication recorder	Behavioral - 1, 3, 5, 6, 9, 10, 13, 15
Visual Test Equipment	Behavioral - 2, 12
Reaction Time measuring device	Behavioral - 1, 2, 3, 4, 8, 12, 13, 15
Tracking Task	Behavioral/Others -1, 3, 4, 7, 8, 12, 13, 14
Post Flight Debriefing	Behavioral/Plus Others - 1, 3, 4, 5, 6, 9, 10, 11, 13, 15
Daily individual diary	Behavioral - 1, 3, 4, 5, 6, 9, 10, 13, 15
Periodic on board behavioral questionaire	Behavioral - 1, 3, 5, 9, 10, 11, 13, 15
Vigilance test device	Behavioral - 1, 3, 12
Blink rate monitor	Behavioral - 1, 3, 11
3/D displacement device	Behavioral - 2, 4, 7, 8, 12, 14, 15
Vehicle activity or event log	Mission Operations - 1, 3, 9, 15
Photogrametric analysis cameras	Behavioral - 2, 3, 4, 7, 8, 14, 15
Short and long term memory device	Behavioral - 1, 3, 11, 13
Audiometer	Behavioral - 12
Cognitive function	Behavioral - 1, 3, 5, 6, 11, 13

Table 1.4 Recommended Behavorial Measurements (Cont)

Test Technique (Continued)	Instrumentation Area Behavioral Barometer (Continued)
Otolith/vestibular mechanism test	Neurological - 2,4,7,12
Keto-steriod analysis	Biochemical - 1,3,5,9
Eosinophil counts	Biochemical - 1,3,9
Sweating profiles	Biochemical/medical - 1,3,9
Body weight	Medical - 4
EMG	Medical - 1,2,3,4,6,8
Heart Rate	Medical - 1,3,4,5,6,9
Blood Pressure	Medical - 1,3,4,5,6,9
Body Temperature (core)	Medical - 1,3,4,5,9
Respiratory Rate/Volume	Medical - 1,3,4,5,6,9
Metabolic Profiles	Medical - 1,3,4,5,6,9
EEG	Neurological - 1,3,6,9
Muscle strength	Muscolo Skeletal - 2,4
Muscle endurance	Muscolo Skeletal - 2,3,4

d. Skill/Training Requirements

e. Lead-time needed for On-Board Methods and Hardware

Procedures which are sensitive, precise and accurate were sought for on-board performance. The results of this trade-off are shown in Table 1-5. Measurements, not included in the latest NASA list, were not evaluated. During the course of in-house and funded studies, more than 250 measurements have been evaluated and the present measurements included in the on-board and preserve categories are sufficient.

Equipment which supports a number of analyses has been stressed, with single-use devices kept to a minimum. Centrifuge, microscope and controlled-temperature storate capability can be used to support a variety of experiments. Addition of a spectrophotometer/densitometer function and radioisotope sensor greatly broadens the on-board analytical capability.

Currently available hardware as well as concepts in various stages of development for automation of biochemical analyses have been considered for possible application to IMBLMS. All commercially available devices are unsuitable for IMBLMS use. However, a research and development effort* sponsored by General Electric is in progress and may well result in hardware applicable to IMBLMS.

Modifications of existing biochemical techniques by simplifying wet chemistries or devising "dry" methods have been evaluated. While all present methods require some modification for flight use, those recommended for on-board use require the least development prior to flight qualification. A sizeable array of additional on-board tests would become available for IMBLMS measurements given an enlarged research and development effort.

*The vendor is not working under this contract, thus the Rights to Data Clause of this contract does not apply.

Table 1-5. Results of On-Board Vs. Post-Flight Analysis Tradeoff

On-Board

- Accurate Fluid Intake
- Sweat Measurement and Sample Return
- Accurate Feces Wet Weight
- Accurate Urine Volume Measurement
- Routine Urinalysis
- Plasma Volume - Plasma
- Hematocrit - Blood
- Hemoglobin - Blood
- RBC Mass - Blood
- RBC Survival - Blood
- Blood Cell Morphology - Blood
- Reticulolyte Count - Blood
- Bleeding Time - Blood
- Clotting Time - Blood
- Lymphocyte Karyotyping - Blood

On-Board with Post-Flight Backup

- Glucose - Serum
- SGOT - Serum
- Bilirubin - Serum
- Alkaline Phosphatase - Serum
- CPK - Serum
- BUN - Serum
- Lactic Dehydrogenase - Serum
- Protein - Serum

Preserve

- Return of Total Dry Stool
- N, Ca, P, Na, K, Cl, Mg - Urine and Feces
- Body Microflora (Cultures)
- Environmental Cultures
- ADH - Urine
- Aldosterone - Urine
- Catechols
- 5-HIAA-Urine
- Hydroxyprolines - Urine
- Mucoproteins - Urine
- Pyrophosphates - Urine
- 17-Hydroxycorticosteroids - Urine
- 17-Ketosteroids - Urine

Preserve (Continued)

- Total Amino Acids - Urine
- VMA - Urine
- Creatine and Creatinine - Urine
- Sulfate - Urine
- Mineral Metabolism by Isotopic Techniques - Serum and Urine
- Glucose - Serum
- Immunoglobulins - Serum
- Fibrinogen - Plasma
- LDH and LD Isoenzymes - Serum
- Transferrins - Serum
- ACTH - Plasma
- Alkaline Phosphatase - Serum
- BUN - Serum
- Ca and PO_4 - Serum
- Cholesterol - Serum
- CPK - Serum
- Urin Acid - Serum
- Calcitonin - Serum
- Parathyroid Hormone - Serum
- Antibody Titrations - Serum
- Bilirubin - Serum
- Complement Titration - Serum
- Electrolytes - Serum
- Protein Electrophoresis - Plasma
- Prothrombin Consumption - Serum
- Free Thyroxine - Serum
- SGPT - Serum
- SGOT - Serum
- Total Body Water - Blood
- Total Protein - Plasma
- Blood Lipids - Serum
- Fibrinolytic Activity - Plasma
- PBI - Serum

Table 1.5. Results of On-Board Vs. Post-Flight Analysis Tradeoff (Continued)

Omit

Histamine - Urine
Metanephrines - Urine
Parathyroid Hormone - Urine
Hemoglobin Electrophoresis - Blood
Methemoglobin - Blood
ADH - Serum
Histamine - Serum
RBC Enzyme Studies - Blood
17-Hydroxycorticosteroids - Blood
TBPA - Serum
Glucagon - Serum
Growth Hormone - Serum
Insulin - Serum
Serotonin - Blood
Thyroid Bound Globulin - Serum
TSH - Serum
RBC Fragility - Blood
WBC Mobilization - Blood
Platelet Adhesiveness - Blood
Bicarbonate - Blood
pH, pO_2, pCO_2 - Capillary Blood
Clot Retraction - Blood

1.7 PRECISION AND ACCURACY

A major consideration in the laboratory evaluation was the precision and accuracy requirement. The major intent of the IMB LMS program is the development of the means for the detection of physiological changes in response to the space environment, not to distinguish the sick from the well individual in the hospital. Such detection should be as early as possible and permit the establishment of trends for prediction to longer missions. To meet this objective, we have established precisions and accuracies in the technique selections at $\pm$ 5%. Further detailed study of individual measurements and their special requirements is needed.

In the electronic area a similar level of precision and accuracy from sensor to ground control has been established. In Volume III, four cases are studied assigning precisions and accuracies through the data link. Five percent appears to be a reasonable objective.

1.8 DATA QUALITY

The overall data quality is subjected to a variety of influences. With the development of new equipments qualified for flight and new procedures as the result of crew safety considerations, a substantial program of validation may be required including double-blind procedures, carefully prepared standards and statistical analysis. A similar validation program will be required to establish the validity of prolonged storage of biological samples and the absence of significant degradation of the materials of interest.

SECTION 2

ANALYSIS OF MEASUREMENT GUIDELINES

2.1 GENERAL BACKGROUND DESCRIPTION

A basic experimental logic underlies the conception of a Medical and Behavioral Laboratory. It is that the crew interacts physiologically and behaviorally with the environment provided than by the design engineer and the mission planner. This environment encompasses the gaseous composition and pressure, the imposed work-rest cycle, the nutritional provisions, the radiation level and a variety of other features which result from analytical, design and test studies. The major physiological and behavioral relationship of the crew with the space environment itself is the exposure to weightlessness, and the effects of this exposure forms the central core of the Laboratory program.

The establishment of a meaningful Laboratory study of the effects of weightlessness on man requires the reconciliation of two divergent views. If the effects of weightlessness are regarded as operationally significant and a threat to the physiological and behavioral integrity of the crew, it is prudent to undertake a series of weightlessness countermeasures in order to control such effects. If such a course is adopted and is successful, the experimental program becomes a validation of the prescribed regimen. However, if the effects of weightlessness are physiologically and behaviorally measurable but not of such a nature as to be operationally significant (this has proved to be the case in the current flight program), the way is open for cautious exploration and the development of a data bank which will permit predictions to extended orbital stay times, optimization of the imposed environment, and the development of criteria for long-term monitoring.

General Electric has followed with great interest the evolution of the NASA Medical and Behavioral Laboratory program from its inception in 1963. This evolution, from the early measurement-oriented studies of Republic and North American to experiment solicitation from the scientific community and their integration in a variety of vehicle concepts (Lockheed, Martin), the winnowing of the experiment list by intense in-house review and the extensive study of one G time lines in the LEM mockup by Lockheed, has resulted in a

solidly-based experimental program. In parallel, the General Electric Company Missile and Space Division in association with the Air Force has conducted similar, but less elaborate studies in relation to the Orbital Space Station System Study and the Manned Orbital Laboratory Program including a thirty-day and a fifteen-day Space Environmental Simulator confinement study and extensive studies of human performance in underwater simulation.

2.2 APPLICATION OF THE NASA MEASUREMENT LIST

The basic design requirements for the Integrated Medical and Behavioral Laboratory Measurement System utilized during this Phase B-II contract were contained in a list of measurements forwarded to the contractors 21 November 1967 by NASA Headquarters; a copy of which is found in Appendix A for contractor analysis and recommendation. Three categories of measurements were provided: a series of measurements which were required; a series which were not required but recommended; and a series for which provision was to be made in the event a specific requirement should arise. A major task of this Phase B-II study has been the critique, revision and refinement of this list.

The proposed NASA experimental measurements are essentially of two types: static and dynamic measurements. Static measurements consist of the systematic collection of data by observation and measurement which, following analysis, will be displayed as a function of elapsed time in orbit or other mission variables. Dynamic measurements consist of the systematic stressing of experimental subjects to produce physiological responses (provocative testing), e.g., the manipulation of an experimental variable to produce a response.

This classification may permit a more orderly identification of major pieces of equipment, the interactions between experiment protocols when they are combined and the sequence of progression or growth of experiment capability. For instance, three major pieces of equipment involved in dynamic experiments are the Exercise Ergometer, the Lower Body Negative Pressure Garment and the Rotating Litter-Chair. Each of these presents problems with respect to the vehicle interface (swept volume, attitude control torques, etc.) and each may serve as a central experiment around which to group static measurements.

Static measurements may be classified according to their progressive complexity, equipment requirements and crew capabilities and training. The classification includes:

a. Pre- and post-flight sampling and measurement, which will be continued in the AAP flight programs.

b. Inflight sampling, preservation storage and return of biological samples.

c. Inflight measurement, recording, display and telemetry including selected biochemical measurement.

d. Inflight data reduction and analysis by the flight crew including computer manipulation of data, data compression and experiment reprogramming.

2.3 USE OF AAP APPROVED EXPERIMENT PROTOLS

The NASA list represents a tabulation of measurements. In order to provide additional contractor guidance, NASA has made available protocols of presently planned AAP medical and behavioral experiments for Flights 1-4. These protocols have been of value, and discussions between GE and the Principal Coordinating Scientists at MSC-Houston have been productive in understanding the probable use of the measurements and the experimenters intent. Many decisions relating to equipment and procedures have been made in the absence of knowledge of the use to which they will be put or the desires of the individual experimentors who will use them on the designated second cluster.

For example, in developing the measurement frequency schedule we have not been able adequately to reflect requirements for two-astronaut participation. Simulation (neutral bouyancy) will be required clearly to establish the effects of weightlessness on performance time. The needs of experimenters for simultaneous measurements, prolonged experiments with periods of subject rest to reach control conditions and desired repetition rates can only be approximated. The establishment of protocols will throw into focus measurement interactions such as incompatibilities in preservation requirements for biological samples, the effects of exercise, sweat loss and calcium balance, the interactions in the use of labeled compounds and the use of exercise and LBNP as provocative tests and countermeasures.

2.4 THE THREAT OF WEIGHTLESSNESS AND THE ARTIFICAL G DECISION

From the operational point of view the long term thrust of the IMBLMS program relates to the threat of weightlessness and the requirement for countermeasures. Among the proposed countermeasure procedures is artifical gravity by spacecraft rotation. The IMBLMS program will test the hypothesis that the physiological and behavioral adaptations to zero G are appropriate and do not affect on-orbit operations and that the earth-based procedures such as neutral buoyancy and bed rest are useful analogies of weightlessness. The threat of zero G, if it exists, relates to G tolerance and vehicle control during reentry and at parachute deployment, landing and capsule egress.

If this threat is real, physiological countermeasures during orbital flight (exercise, lower body negative pressure) and crew protective devices (elastic leotard, G-suit) during reentry must be evaluated before recourse to the difficult design solution of spacecraft rotation.

2.5 MEASUREMENT CATEGORIES

For this report the measurements have been divided into three major categories:

a. Physiological measurements

b. Laboratory Analyses

c. Behavioral Measurements

In Phase B-II, major emphasis has been placed on defining the laboratory evaluations and behavioral measures and in the implementation of the physiological measures.

2.5.1 PHYSIOLOGICAL MEASUREMENTS

These measurements have been divided by body functional systems. In this category we include neurological, cardiovascular, respiratory, metabolic and nutritional measurements. They reflect a balanced approach to the physiological effects of prolonged weightlessness as described above.

2.5.1.1 Neurological Measurements

In the neurological area we are impressed with the advanced state of development of rational techniques, procedures and hardware for the conduct of meaningful measurements. These measures are directed towards the adaptations of the vestibular system primarily to weightlessness. Results of these studies will not, however, bear upon the artifical G decision which depends upon data developed in the cardiovascular and other areas.

2.5.1.2 Cardiovascular Measurements

Adaptations to weightlessness will be first revealed in cardiovascular variables. Although instrumentation for many of these variables is primarily electronic, the requirement for the use of non-invasive methods has a significant effect on precision and accuracy. The use of exercise to establish the level of physical fitness and the LBNP to establish the level of adaptation to hydrostatic forces form the central test procedures. We strongly urge a measure of leg circumference in order to describe venous compliance on the basis that a major target organ for zero G adaptation is tne venous system. We recommend the use of the transcutaneous Doppler flowmeter system because of its versatility in measuring flow in many locations and its convenience for astronaut use. Research is active with this instrument and although its limitations as a flowmeter, e.g., vessel diameter change, are known, it appears as the major candidate at this time. Facilities for the indirect Fick are also provided. Our studies have not supported the inclusion of the impendence cardiac output system because of accuracy, and precision problems discussed in detail in our Phase B-I report.

From the safety point of view we cannot support arterial puncture or venous catheterization. Caroted sinus stimulation appears a risky procedure. We have studied ballistocardiography and find it to be a relatively pure research study within the space flight context and depending upon the protocal selected, a heavy load on the data management system.

2.5.1.3 Respiratory Measurements

Respiratory variables are required in the evaluation of physical fitness and general metabolism. Although we recognize the potential alterations in respiration function which may ensue from the altered atmospheric pressure and composition, the possible redistribution of blood in zero G, and the ascent of the viscera, these changes

represent an operational threat particularly where an inert gas is present in the atmosphere as planned for AAP. A general investigation of man in space, however, should seek data related to respiratory function, the occurrrence of atelactasis and shunt, evidence at uneven ventilation, airway potency, lung mechanical properties and altered diffusion.

2.5.1.4 Metabolism and Nutrition

Metabolic and nutritional measures are second only to cardiovascular measures in the physiological area. Not only are quantitative data required for logistics purposes but the general health and well-being may best be measured by water and food input-output estimates coupled with accurate measures of body weight.

In the NASA measurement list the IMB LMS contractor is asked to "provide for":

1. Accurate urine volume and fluid intake measurement
2. Accurate wet weight of feces and the return of dry stool and
3. The return of all food packages marked by date, time and individual.

GE has interpreted these requirements in terms of the development of appropriate specifications. In our interpretation the equipments which perform these functions are GFE and at present are not clearly defined. IMB LMS provides a services interface in terms of power, pneumatic source and data management. At present preservation and storage capability for fecal and food residue is not included in IMB LMS.

IMB LMS will provide a growth capability to extend the understanding of mineral metabolism by isotopic methods and the quantitative measurement of demineralization by bone densitometry. Studies in gastrointesterial physiology, now under intensive consideration in the USSR, will be extended in the future and IMB LMS will accommodate an endoradiosonde.

2.5.2 LABORATORY EVALUATIONS

The potential for broadening and deepening the understanding of the physiological effects of prolonged weightlessness by on-board analysis, or by preservation, storage and return

of biological samples formed a major element of the GE Phase B-II study. For this study, the ground rules of a 1971 launch date and the presence of a "medically trained" astronaut in the crew lead to a reappraisal of the Phase B-I conclusion that all specimens should be stored.

In considering which of the proposed measurements might be considerates for on-board analysis a significant consideration was the accuracy, prevision and sensitivity of available techniques. IMB LMS must address itself to the detection of physiological changes related to exposure to the space environment. For this purpose, accuracies and precisions beyond that required in the clinical hospital laboratory are required. In the latter environment tests are directed towards distinguishing the sick from the well individual. The requirement for 15 percent accuracy, which would permit detection of early changes and extrapolation to long term missions, has severly limited the selection.

Each measurement has been examined in terms of physiological significance, complexity of equipment and procedures, crew skills and training required, safety, redundancy or overlap of the measurement with others and hardware development lead times. We have reviewed the state-of-the-art in equipment and techniques for the conduct of automated chemical analysis in space. No commercial instrument meets the IMB LMS requirements for performance of precision, accurate measurements on a wide variety but generally limited number of samples. Such equipment has been developed to handle hundreds of a limited number of wet chemistries per day. Other techniques using paper tapes (Natelson) and premixed regent kits (Dade, Harleco, SKI) have been examined and eight measurements are proposed using these later measurements. Twenty-four measurements are proposed for omission from the current list. The balance are recommended for storage and post-flight analysis.

The biochemical, hematological, cytological micriobiological and immunological measurements, whether performed in flight or post-flight, require an extensive array of expendables for sampling and sample preparation. Based on the measurement frequency schedule developed during this study approximately 12.25 lbs per week are required to support such studies as initial on board stocks or by resupply.

The quality of the data that may be obtained will be subject to a variety of influences. Because new, flight-qualified equipment will be used and, in some cases, new techniques evolved, a program of validation of both equipment and methods will be required involving double blind procedures with carefully prepared standards and statistical analysis. Degradation of biological samples subjected to prolonged storage in orbit, during reentry and transport to ground-based laboratories requires investigation. Finally all techniques and procedures must be consistent with astronaut capabilities.

2.5.3 BEHAVIORAL MEASUREMENTS

In contrast to the NASA measurements proposed in the physiological and laboratory evaluation areas, the techniques and procedures provided under the behavioral heading are extremely general. To provide substance and rationale for these measurements s "tops-down" analysis was performed. From mission operations requirements, vehicle and equipment constraints and the nature of the space environment, potential behavioral modifications and their manifestations were developed. From these measurement techniques, procedures and equipment requirements were defined. The measurements were then distributed among the board NASA categories.

Because no single measure of a single parameter is adequate to define may behavioral area, individual techniques and procedures have been grouped in fifteen functional behavioral areas and the contributions of the physiological correlates, measurements were then distributed among the broad NASA categories.

Because no single measure of a single parameter is adequate to define any behavioral area, individual techniques and procedures have been grouped in eleven functional behavioral areas and the contributions of the physiological correlates, measured elsewhere in IMBLMS, indicated. In this section of the report certain new instrumentation alternatives are described which appear promising but developed too late for incorporation in the baseline system.

2.6 MEASUREMENT DOCUMENTATION

The following sections of this volume contain general discussions of the underlying the selection of measurements and equipment. In Appendices A, B, and C, GE recommendations are set forth in detail. For each measurement three documents have been developed: a Measurement Specification (Appendix A), a function flow Block Diagram (Appendix B), and a Human Engineering Worksheet (Appendix C).

2.6.1 MEASUREMENT SPECIFICATION

Each specification contains the following information:

a. Measurement name, purpose and recommended technique.

b. Measurement function flow back diagram including stimulus, sensor signal conditioner, computation, control and signal utilization.

c. Input Signal Characteristics.

d. Stimuli and Calibration Requirements.

e. Onboard Output Characteristics.

f. Ground Output Characteristics.

g. Advanced evaluation techniques which may impose a change in signal processing.

h. Support Characteristics.

i. Environmental Data Requirements.

j. Estimated times to set up, perform and secure.

k. Estimated Measurement Frequency.

2.6.2 HUMAN ENGINEERING WORKSHEET

For each measurement the crew requirements for performance are elaborated under the following headings:

a. Measurement technique description.

b. Human engineering design requirements including operations, maintenance and safety.

c. Human performance requirements including task requirements, equipment requirements (displays, controls and support equipment).

d. Environment requirements including lighting, restraint, work-space, etc.

e. Time Requirements.

f. Training requirements including capabilities, skill, knowledge and training methods.

g. Potential Hazards.

2.7 SUMMARY

The revision of the NASA measurement list detailed in this report has been used to define a baseline IMBLMS concept. Two alternative concepts also have been developed using only selected measurements and subserving different and more limited purposes. The list in its present form, we believe, adequately meets the NASA objectives of providing the medical and behavioral data needed to assume crew survival and performance during the prolonged missions contemplated.

SECTION 3

BIOMEDICAL MEASUREMENTS

The biomedical measurements chosen for inclusion in the IMBLMS design and including all three areas of observation have had to meet several selection criteria.

Foremost among the criteria considered has been the safety and well being of the subject astronauts, within the limited background of information available (state-of-the-art) for the several measurements. Great emphasis has been placed on safety through use of non-hazardous equipment and reagents. Protection against electric shock potential, the flammability, noxious nature and volatility of the potential reagents have been considered along with the possible explosiveness of any chemical system. Safety monitering though listed as GFE is a prime responsibility and concern of all involved.

IMBLMS by definition is an information gathering system and as such we can foresee many useful techniques and improvements evolving in both the state-of-the-art and philosophies for future advancement. In the area of Clinical Laboratory analysis alone we hope that the IMBLMS effort may bring about some additional standarization of techniques with improved accuracies. Our general knowledge of effects on behavior and physiology of closed ecological systems at zero G should with IMBLMS be advanced to a point where feasability of future space explorations of long duration can more easily be resolved.

The impetus provided by the IMBLMS requirements should lead to new philosophies of methodology in meeting every increasing health needs. New ideas, techniques and equipment for measurements will evolve. A great need for uniformity in the area of laboratory analysis will be fostered by the very nature of the system.

This impetus also will overflow into the physiological areas with the increasing need for development of unique biomedical instrumentation. Items, currently envisioned only as conceptual drawings, will soon become integral components of working diagnostic

equipments. What effect these might have on the future health and welfare of the general populace can only be open to conjecture. We believe however, that IMBLMS will be a vital contribution to many areas of health improvement in addition to the currently proposed space missions.

The field of mental health also stands to gain insight into what may occur in closed ecological systems, whether at zero G or not, and could have long term social implications in such areas as environmental and especially underwater studies.

3.1 SUMMARY OF PHYSIOLOGICAL MEASUREMENTS

The physiological measurements discussed below include all techniques, procedures and equipments listed under the NASA headings of neurological, cardiovascular, respiratory, metabolism and nutrition with the exception of the laboratory evaluations proposed in each area which are covered in Section 4.0. Relationships with the behavioral area are described in Section 5.0.

In general, techniques, procedures and equipments for the performance of physiological measurements are further developed than in the other areas. However, the requirements to minimize complexity, crew skills and training required and hardware lead times and to maximize safety has lead to the adoption of a non-invasive approach to physiological measurement. This approach cannot help but have an effect on precision and accuracy. In some case, the precision and accuracy of in flight tasks can only be improved by the conduct of preflight ground control invasive studies on the individual astronaut who is to be measured in orbit.

The proposed NASA measurement list is a well-balanced one. In only a few cases do we take exception to the inclusion of individual measurements in this area for the reasons stated in the descriptions which follow.

3.1.1 MEASUREMENT SELECTION

In order to assess objectively the relative importance of measurements in the physiological element, a trade-off was performed. There were six trade-off parameters. (See Tables 3.1-1, 3.1-2, and 3.1-3.)

Importance for future space missions was the most heavily weighted parameter. It is not the function of IMBLMS to support scientific research per se. Rather, it should be keyed to the measurement of those parameters which will, to a large extent, determine man's performance in space. If a measurement technique was a secondary method of determining information it would rank low in this area.

Probable inclusion in experiments was a difficult item to determine. The existing experiment protocals were reviewed, and a best estimate of measurements included in future experiments was made. The estimate of measurements included in many experiments formed the basis for this parameter.

The measurement rankings under accuracy include deductions not only for inherent equipment errors, but also for operator inaccuracies inherent in the measurement technique.

Commonality of equipment played a large role in the selection of measurement techniques. This is manifested in the trade-off. Also considered in equipment selection was ease of set-up and performance. All of the recommended techniques in the physiology element may be performed by a medically trained corpsman with minimal additional training. Some, however, require more patience and care than others.

Safety is probably the most important consideration in the initial selection of measurement techniques. Any unsafe measurement was immediately eliminated from further consideration. Even though all of the recommended measurements are safe, a great deal of design effort is being directed to subject protection.

We have concluded, on the basis of the factor discussed above, that a ranking of measurements is a necessity. This enables us at any time to see quickly the relative merits and problems of each and to be prepared to adjust IMBLMS more intelligently to any of the various vehicles or mission profile that may be required.

3.1.2 CLINICAL EVALUATION

The total concept of the recommended IMBLMS system and program is shaped around the premise that total biomedical evaluation of man's functional capability in space is of prime importance during extended periods of weightlessness. One of the prime requisites of such an evaluation should be the clinical assessment of the individual subject from day to day. It is proposed that IMBLMS include the "software" to make this possible. In addition to the regular medical kit, simple history and physical check lists will be provided along with the necessary instructions and minor equipment (tongue blades, etc.) to make them easily usable.

3.1.3 MEDICAL KIT

An important part of the IMBLMS program will include the provision of a supplemented medical kit. Provisions has been made for the storage of such a kit and instruction for the use will be included where needed. GE in considering the basic medical kit to be GFE and to contain the items described in table 3.2.1-1 on page II-6 of NASA MSC specification CSD-A-29[illegible]. In addition, we recommend the addition of certain simple examination devices such as tongue blades, a reflex hammer, an oto/ophthalmoscope, etc. We believe that the clinical evaluation needs of the IMBLMS concept require such supporting equipment but we feel even more strongly that it must be carefully selected for ease of use and practical clinical value.

3.1.4 CREW SAFETY MONITORING

IMBLMS can, if desired, accommodate crew safety and enviromental monitoring without prejudice to any other functions desired of the system. All of the usual crew safety parameters will be measured at various times by IMBLMS due to specific IMBLMS requirements, so safety monitoring per se would require no additional complexity, size, or weight of equipment except interface junction boxes that might be necessary at various locations throughout the vehicle complex for the confenience of the astronauts and to insure no lack of information from any given area or during any unusual activity (EVA, etc.). While we do not formally propose that IMBLMS include safety and environmental monitoring, provisions have been made to perform this function if desirable.

3.2 NUEROLOGICAL MEASUREMENTS

The nuerological measurements on the proposed NASA list may be divided into broad areas: (1) the acquisition of data related to gravity receptors and changes in judgments of spatial location during prolonged absence of gravity; (2) a test of the hypothesis that semicircular canal function may change under weightlessness; and (3) a study of the electroencephalogram as an indication of sleep state as correlated with stimulus material and activity; and (4) a clinical neurological examination.

Table 3.1-1. Cardiovascular and Neurological Measurements

Measurement	Importance For Future Space Missions 0-20	Probable Inclusion In Experiments 0-10	Accuracy 0-10	Commanality Of Equipment 0-10	Ease Of Set-Up Performance 0-10	Safety 0-10	Total
CARDIOVASCULAR							
1. ECG/VCG	19	10	9	10	8	9	65
2. Phonocardiogram	18	10	9	7	8	9	59
3. Cardiac Output	15	8	8	8	7	9	56
4. Arterial Blood Pressure	16	9	8	4	7	9	53
5. Blood Flow	15	7	7	8	6	9	52
6. Peripheral Venous Pressure	15	5	8	3	8	10	51
7. In Flight Exercise	14	8	8	6	6	9	51
8. Rheology	16	4	7	4	7	8	47
9. LBNP	15	7	7	2	6	8	45
10. Venous Compliance	15	7	7	2	6	8	45
11. Ballistocardiogram	11	1	8	4	7	9	40
12. Carotid Sinus Stimulation	Not Recommended (Unpleasant, Unsafe Technique)						
13. Central Venous Pressure	Not Recommended (No Suitable Technique)						
14. Elastic Leotards	Not Recommended (Cannot Satisfy MSC-A-D-66-3)						
NEUROLOGICAL							
1. Agravic Perception	18	9	9	4	6	9	55
2. Ocular Counter Rolling	14	9	9	5	7	9	53
3. Oculogyral Illusion	11	8	9	6	7	9	50
4. Visual Task With Head Rotation	14	9	8	4	7	8	50
5. Electronystagmogram	13	4	9	5	9	9	49
6. Angular Acceleration Threshold	8	6	8	6	6	9	43
7. EEG	7	4	7	5	9	9	41

Table 3.1-2. Metabolic and Respiratory Measurements

Measurement	Importance For Future Space Missions 0-20	Probable Inclusion In Experiments 0-10	Accuracy 0-10	Commanality Of Equipment 0-10	Ease Of Set-Up Performance 0-10	Safety 0-10	Total
METABOLIC							
1. Core Temperature	20	9	10	10	10	10	69
2. Body Mass	16	7	8	6	6	9	52
3. Muscle, Size and Strength	16	6	9	2	8	10	51
4. EMG	10	5	9	10	7	9	50
5. Energy Metabolism	16	6	8	2	5	10	48
6. Endoradiosone	Not Recommended (No Information on GFE Equipment)						
RESPIRATORY							
1. Resp. Rate	16	9	9	8	8	9	59
2. Lung Volume	17	9	9	8	6	9	58
3. Pressure, Flow, Volume	14	8	9	8	7	9	55
4. Breath-By-Breath O_2 Consumption CO_2 Prod.	15	8	7	8	6	9	53
5. Alveolar-Arterial O_2	12	7	6	7	5	9	46
6. Ventilation	10	6	7	8	6	9	46
7. Diffusion	10	6	7	8	6	9	46

Table 3.1-3. Physical Fitness Variables, Means, and Standard Deviations

		Mean	SD
1.	Max O_2 intake, liters/min	3.126	.541
2.	Max O_2 intake, ml/kg body wt/min	39.460	7.550
3.	Max O_2 intake, ml/kg lean body mass/min	54.310	8.260
4.	Max min vol, vent/liter	94.160	21.480
5.	Forced VC/liter	4.960	.680
6.	Ht, cm/FVC per liter	36.090	4.500
7.	FVC/body surface area	2.560	.310
8.	MBC/liter per min	141.120	20.250
9.	Forced expiratory $vol_{1.0}$ (% of VC)	74.390	7.560
10.	Submax resp rate/min	23.530	6.350
11.	Max resp rate/min	33.420	8.440
12.	3-Min recovery pulse count after submax exer	336.020	42.080
13.	Pulse increase from rest to submax	88.350	15.670
14.	Duration bicycle ride, in min	9.600	1.440
15.	Mod Schneider index	18.870	9.100
16.	Resting systolic blood press, mm Hg	119.250	10.530
17.	Postexercise systolic blood press	165.190	17.830
18.	Recovery systolic blood press	126.420	11.460
19.	Resting diastolic blood press	80.560	8.330
20.	Postexercise diastolic blood press	74.820	9.020
21.	Recovery diastolic blood press	80.190	8.600
22.	Resting pulse press	38.630	8.000
23.	Postexercise pulse press	90.430	15.240
24.	Recovery pulse press	46.170	9.400
25.	Max heart rate/min	176.700	13.170
26.	Lying heart rate/min	68.180	9.520
27.	Age, in years	36.900	7.750

VC = vital capacity; FVC forced vital capacity; MBC - maximum breathing capacity.
(J. APPLIED PHYSICAL, 20:991-999, 1965)

Table 3.1-3. Physical Fitness Variables, Means, and Standard Deviations (Cont)

		Mean	SD
28.	Height, in cm	176.403	6.604
29.	Weight, in kg	80.155	10.295
30.	Vent equiv (vent liters/liters O_2 used during max effort)	30.140	4.120
31.	O_2 pulse, ml/min (max exer)	17.810	2.810
32.	Body temp increase during submax exer	.440	.150
33.	Pull-ups	3.760	2.950
34.	Sit-ups	33.430	10.390
35.	Standing broad jump	79.870	8.670
36.	50-yd dash	7.590	.680
37.	Shuttle run	10.520	.880
38.	Medicine ball put	31.740	4.250
39.	Dips	3.630	2.930
40.	600-yd run-walk	146.480	26.790
41.	Drop-off index	55.650	21.420
42.	Force platform-vertical	1261.000	516.000
43.	Force platform-frontal	298.000	157.000
44.	Force platform-vertical/kg body wt	16.300	7.270
45.	Force platform-frontal/kg body wt	3.650	1.720
46.	Submax exer heart rate/min	157.180	14.870
47.	Submax min vol vent/liter	59.500	10.960
48.	Submax O_2 intake, liter/min	2.917	.411
49.	Standing heart rate/min	80.610	10.400
50.	RQ (submax exer)	.971	.067
51.	Lean body mass, kg	127.210	13.270
52.	Percent lean body mass	72.720	6.730
53.	Submax min vol vent/kg body wt	.755	.171

VC = vital capacity; FVC = forced vital capacity; MBC - maximum breathing capacity.
(J. APPLIED PHYSICAL. 20:991-999, 1965)

In general, vestibular measurement is in an advanced state development as described by the Experiment Implementation Plan for M131, Human Vestibular Function.

The Rotating Litter Chair is considered to be GFE and IMBLMS will make provision to provide services, such as power, and to support the experiments by data handling.

While the clinical evaluation procedure is GFE, it will be necessary to establish the fact that the crew member has a properly functioning peripheral neuromuscular and reflex system.

Further sensory and motor studies with considerable neurological significance are described in the Behavioral Section (5.0).

While little modification can be justified for some of the CNS morphological test, many of the neuromuscular reflexes (achilles, patella, abdominal) relate directly to the maintenance of the upright posture of standing and walking. It would be of interest to note any changes in sensitivity or responsivity.

3.2.1 AGRAVIC PERCEPTION

3.2.1.1 Recommendations and Rationale:

The crew member's ability to maintain an appropriate spatial location in the absence of gravity is of major import. Inconsistancies in his ability to orient himself in his surroundings would be both distracting and disruptive of effective operations.

While man in a one-G field utilizes three disparate mechanism to give him information regarding his orientation on entry into zero G he may experience a reconfiguration of feedback from all three. These systems are vestibular systems (the otolith primarily), musculoskeletal stretch receptors and, influence of information from the visual field.

Information is generated in the vestibular system by the otolith which is dependent on gravity to physically align a weighted hair which in turn distorts a sensor providing the needed orientation information. Information arising in muscles, tendons and joints on mechanical

stressors generated by the "weight" body parts involved or during voluntary displacement against the resistance of the gravitational field. The visual field analyses the organizational content of items in the field providing information for making decisions on dynamics of moving objects. Astronauts report reflexive reach "under" free floating objects to "catch" them in anticipation of their "falling".

Demonstrated gravity related, visual illusions common to high dynamic, non-linear aircraft operations, or visual distortions due to Ganzfeld or displaced referents, more than justifies careful, complete description and measurement of man's ability to orient himself in the absence of gravity.

3.2.1.2 Technique Selection and Rationale

Measurement techniques developed to provide information regarding the crewman's ability to develop alignments in respect to an internal referent as well as in respect to the vehicle interior are both useful. However, additional information could be gathered utilizing essentially the same techniques. It would be highly desirable to establish what frame of reference the crewman would utilize when no formal instruction was given. Amorphous instructions to point "upward" when the subject was intra-vehicular and extra-vehicular, eyes open, eyes closed, restrained, free floating, "reclining" and "seated" in reference to the cabin interior would be useful.

Information derived in this area could be utilized in the organization of hardware and displays as well as providing a basis for the development and implementation of certain task procedures.

3.2.2 OCCULAR COUNTER-ROLLING

3.2.2.1 Recommendations and Rationale

The primary objective behind measurement of occular counter rolling is to evaluate otolith function as related to degree of tilt. At the present time, no formal perceptual function has been identified with the presence or absence of a counter-rolling capability.

The purpose of attempting to elicite a counter-rolling response is to attempt to relate causality to otolithic alignment by gravity. This premise is based on the assumption that an absence of response during "tilting" would imply that when counter-rolling is absent is directly related to otolith function.

3.2.2.2 Technique Selected and Rationale

The basic technique established for ground testing should be attempted essentially unchanged if comparisons are to be made. If under strong cue conditions some form of associative reflex could be activated to produce counter-rolling, the theory of complete otolith control of the response would have to the modified. If counter-rolling occurs under these conditions then second level effects would have to be implicated. Care must be taken during "tilt" displacement to prevent high rates of acceleration to cause otolith realignment as a function of inertial or centrifugal force.

3.2.3 OCCULOGYRAL ILLUSION

3.2.5.1 Recommendations and Rationale

Inclusion of the test is directed at the detection and quantification of alterations from baseline sensitivity and response in labrynthine function. The problem is whether or not there will be a desensitization because of atrophy of disuse or a lowered threshold or increased response due to a Weber-Fechner function that predicts the ambient baseline is zero and any moderate increase in function will produce a massive response.

Measures to quantify threshold sensitivity and extent of related response are required.

3.2.5.2 Technique Selection and Rationale

No major measurement changes from those described in the approved M131 experiment is advocated except for the Human Engineering criteria developed in the Human Engineering Work Sheets appearing in the Appendix.

3.2.4 VISUAL TASKS WITH HEAD MOTIONS

3.2.4.1 Recommendations and Rationale

In the Slow Rotating Room (SRR) at Pensacola standarized procedures have been developed for assessing task performance involving head motions in a rotating environment. Tasks consist of switches and dial settings performed in sequence and at a variety of locations above and below the subject. In order to activate these manipulanda head motions of specific rates and directions are involved.

In zero-G environment, the coupling of head velocity with ambient angular velocity to produce coriolis stimulation of the labyrinth should be minimal. Such a test is more suited to assessment of human performance in a rotating spacecraft or one in which rather extensive and frequent high velocity attitude changes are anticipated.

3.2.4.2 Techniques Selected and Rationale

The manipulanda required could be built into the Rotating Litter Chair if required. Alternately, the operation of the IMBLMS console itself could be used.

3.2.5 ELECTRONYSTAGMOGRAM

3.2.5.1 Recommendations and Rationale

Inclusion of the test is directed at the detection and quantification of alterations from baseline sensitivity and response in labrynthine function. The problem is whether or not there will be a desensitization because of atrophy of disuse or a lowered threshold or increased response due to a Weber-Fechner function that predicts the ambient baseline is zero and any moderate increase in function will produce a massive response.

Measures to quantify threshold sensitivity and extent of related response are required.

3.2.5.2 Technique Selection and Rationale

No major measurement changes from those described in the approved M131 experiment is advocated except for the Human Engineering criteria developed in the Human Engineering Work Sheets appearing in the Appendix.

3.2.6 ANGULAR ACCELERATION THRESHOLD

3.2.6.1 Rationale for Inclusion

Distortions in the sensation of movement or illusions in this area would have major import during rendezvous and docking operations.

The necessity to establish the time course and direction of any such change in sensitivity would be critical to mission success and function. Once more the dilemma of whether the effect of prolonged residence causes desensitization via atrophic responses or hyperactivation and lowered thresholds via a Weber-Fechner function appears.

3.2.6.2 Technique Selection and Rationale

The availability of a technique to measure threshold sensitivity and response magnitude is available for M131 and no notable additions are considered.

3.2.7 ELECTROENCEPHALOGRAM

3.2.7.1 Recommendations and Rationale

IMBLMS as designed by GE is prepared to accommodate electroencephalogram measurements. These are proposed specifically to provide additional information concerning critical function for neurological and behavioral purposes but also a valuable adjunctive input in the area of basic crew conditioning. Coupled with information from other measurement techniques (GSR, etc. if desired) the EEG provides the best known method of assessing stages of sleep while at the same time not inconveniencing the individual subject being observed.

3.2.7.2 Processes

Several alternate electrode systems and data handling processes have been studied. Ideally, for complete diagnostic purposes, 9 electrode pairs would be recommended. For clinical use, 4 electrode pairs are probably a recommendable minimum. For IMBLMS however, we recommend one electrode pair (plus a separate common ground). We agree with our consultants that under the conditions of the missions as now planned, this will provide us the information necessary for assessment of sleep state, general cortical activity, and evoked responses if desired.

3.2.7.3 Data Management

The IMBLMS data management system has been designed to record and process the EEG information obtained and to prepare it for transmission.

3.3 CARDIOVASCULAR

Cardiovascular measurements represent probably the most sensitive indication as to the physiological status of the individual astronaut. The capability of the human body to sense some slight changes in environmental condition and its ability to adjust the cardiovascular system accordingly (either overall or regionally) make these an unusually valuable source of information. Therefore, while not suggesting a lesser value for measurements of other types, this analysis has concluded and does suggest a strong emphasis on the cardiovascular system.

One of the major concepts enbodied in the recommendations presented here is that of commonality of purpose and use of equipment (see Volume I, and Volume III). Most of the measurements described require sensors applied to the skin of the subject, but in many cases such sensors can be shown to be common to more than one measurement. Each individual measurement description considers this point. Of course the same is true of power supplies, signal conditioning, signal processing, signal storage, display and other equipment. (See Volume III)

The arrangement of recommended measurements as they appear in order in this report reflects the relative clinical significance as balanced against the safety, complexity, difficulty, size weight, cost, etc. for each one considered. Functional flow block diagram for each one can be found in Appendix B and detailed specification sheets for each one in Appendix A.

3.3.1 ELECTROCARDIOGRAM/VECTORCARDIOGRAM

3.3.1.1 Recommendation and Rationale

The electrocardiogram is a key cardiovascular measurement since it provides direct information on the electrical activity of the heart the signal can readily be manipulated to give heart rate and in association with other measures inferentially supplies information on the force of contraction and the metabolic state of the heart. A system designed to provide one to three channels of ECG information at a given time using a common set of electrodes is recommended.

3.3.1.2 Techniques Selected and Rationale

3.3.1.2.1 Electrodes

GE has investigated the use of the Schmitt-Kilpatrick active electrode and the USAF School of Aerospace Medicine insulated electrode. They are similar in that an integrated circuit follower amplifier is built into the electrode itself. This greatly reduces electrode output impedance, permits the use of low input impedance amplifier and also lessens pickup noise problem. These electrodes have several important drawbacks, however.

a. The circuits on the electrodes require power and return wires. Therefore, there are three times as many wires on an already "busy" harness.

b. The signal conditioners proposed for IMBLMS have common mode rejection ratios in excess of 80 db thereby already reducing lead pick-up.

c. Reliability of these electrodes is questionable. The electrodes have an inherent variable skin to electrode capacitance. Because of the very large input impedance of the follower circuit, significant low frequency information may be lost.

Because of the environment in which these measurements will be made, and because of the superior quality of the signal processing equipment being recommended, the electrodes recommended are the standard silver-silver chloride "button" type, carefully applied pre-flight and worn continually. Careful studies have shown that the frequent application, removal, and reapplication of electrodes is much more likely to cause skin irritation than carefully

applied electrodes left in place. Variation in impedance from measurement to measurement is greatly reduced when the electrodes are left undisturbed. Because of the proposed duration of the IMBLMS missions, we believe these to be extremely important considerations.

It is proposed that all sensors (including, the microphone outlined in 3.3.2 and the blood pressure cuff and microphone in 3.3.4) be left intact throughout the mission. (An exception to this will be discussed where the Doppler technique is considered). We propose as a safe-guard however, that each sensor location be identified with an indelible mark pre-flight and that instructions and materials be included to allow the reattachment of a sensor should it somehow be accidentally disloged.

A specially designed electrical harness is recommended to connect the subject sensors to the data handling equipment. Harness specifications require no physical impariment of the astronaut's activity or any increased discomfort. Quick disconnect fittings are recommended at a point attached to the astronaut's clothing so that he may be tied in to the data handling system at any of the several locations in the spacecraft where it will be important to perform the measurement.

3.3.1.2.2 Frank Lead System

The Frank lead system for Vectorcardiography was studied for incorporation as a part of IMBLMS. The Apollo Vectorcardiograph system requires seven single purpose signal electrodes in addition to a signal ground electrode. A resistance network is used in conjunction with three ECG Amplifiers to orthogonalize the signals from these electrodes. In order to minimize the number of electrodes, a system which uses only four single purpose VCG electrodes, plus one electrode of these used for Electronystagmogram measurements, one of these used for Electromyography and the system ground electrode was studied. The electrodes themselves may be placed orthogonally and the electrode harness is thus simplified. The suggested placement of electrodes are given and further engineering details in Section 4.1.

It should be noted that the presence of a computer enables the transformation of these orthogonal components into the Frank or any of the clinical ECG components. We recognize the highly extensive nature of the ground control studies utilizing the Frank lead system, but we feel that the work of Schmitt and others using a system such as we describe supports the clinical and scientific merit of the simplified network.

3.3.2 PHONOCARDIOGRAM

3.3.2.1 Recommendation and Rationale

The phonocardiogram is important to the system because of the additional information it provides as to cardiac cycle timing and heart valve function. It will normally be observed simultaneously with the electrocardiogram, the vectorcardiogram, the blood pressure, and/or the ballistocardiogram.

3.3.2.2 Technique Selected and Rationale

The recommended microphone (GFE) has an acceptable flat frequency range of 30 to 100 Ha. A microphone with a flat response to O Hz has been identified but a cut-off at no less than 30 Hz is desirable to avoid picking up extraneous skin and muscle noise. It is recommended that the total signal be delivered to the observer in the classical form, but provisions have been made to process it further and present the "envelope" of the rectified signal should this latter seem desirable.

3.3.3 CARDIAC OUTPUT

3.3.3.1 Recommendation and Rationale

The assessment of cardiac output and indeed blood flow in general represents a serious problem. In the IMBLMS study we have sought a simple, inexpensive device for routine nondestructive flow measurement with a high degree of accuracy, stability, reproducability, sensitivity and range which could be used on humans without discomfort, hazard or damage to the skin. This optimistic statement of objectives cannot at this time be met.

Rushmer, Baker and Stegall have reviewed the available devices for blood flow measurement against an extensive list of criteria. The general methods included plethysmography, pressure gradient, indicator transport, indicator dilution, thermal and transcutaneous Doppler methods. They present the relative merits to show that each type has both advantages and disadvantages with reference to both accuracy and utility. For IMBLMS, techniques requiring arterial cathetarization were considered not applicable. If the specifications call for truly non-destructive techniques (without damage to the skin), the choice is drastically limited to occulsion plethysmography, the thermal flowmeter (skin only) and the transcutaneous Doppler flowmeter.

3.3.3.1.1 Transcutaneous Doppler Flowmeter

Plethysmography and thermal flowmeters are generally familiar but the transcutaneous Doppler flowmeter is a relatively recent and very promising development. The Doppler shift principle of blood velocity sensing is very simple. A beam of 2-5-Mc ultrasonic waves is directed diagonally through the blood. A small fraction of this sound is back-scattered from particles in the blood to reach the receiver crystal (Figure 3.3-1). If the blood is motionless, the back-

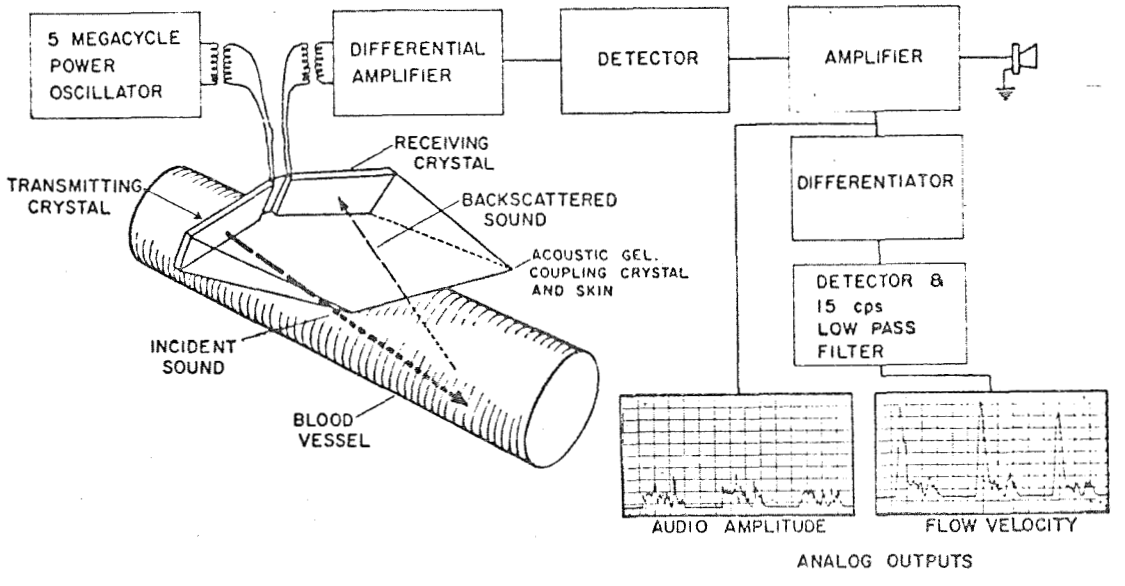


Figure 3.3-1. Transcutaneous Doppler Flowmeter Block Diagram

scattered sound has precisely the same frequency as the transmitted sound. If the blood is moving, the frequency of the back scattered sound is shifted by an amount related to the velocity of the particles. Mixing the back scattered sound frequency with the transmitter frequency produces beat frequencies related to the flow velocity of the blood. Flow velocity in centimeters per second can be predicted accurately from the frequency shift and the angle subtended between the axis of the tube and the transmitting and receiving crystals in accordance with a Doppler shift formula.

Only with knowledge of the cross-sectional area of the channel can the volume flow be accurately estimated from the mean flow velocity. Implanted flowmeters by their nature produce and maintain a constant cross-sectional area. Conversion to a transcutaneous device, therefore, requires compromise with respect to accuracy, reliability and uniqueness of the measurements. The vessel is not confined and small translational displacements can occur. The device therefore is inherently a velocity-meter rather than a volume flowmeter.

Despite its limitations the transcutaneous Doppler method has many favorable characteristics such as flexibility, versatility and convenience.

3.3.3.1.2 Venous Occlusion Plethysmography

This method is commonly regarded as a standard and provides data with as high a degree of quantitative accuracy as the Doppler method described above. Plethysmography was considered in detail in the IMBLMS Phase B-1 final report. Since that time Biosystems, Inc. has re-studied the problem and now recommends a positive pressure air plethysmograph to circumvent previous problems of thermal control, gas reservoir, etc. In discussing venous occulsion plethysmography and the sources of uncertainties in such measurements Rushmer points out how the Doppler flow meter has served as a valuable adjunct and stresses how one type of measurement device can contribute to the understanding of others.

3.3.3.1.3 Impedance Methods.

In the GE IMBLMS Phase B-I report present impedance methods for the measurement of cardiac output were discussed in detail. The potential errors of the system appear insurmountable and the method has not received further study in Phase B-II.

3.3.3.1.4 Rebreathing Method (Indirect Fick)

The necessary gas measuring sensors and devices are incorporated under Respiratory Measurements (Section 3.4). The technique is well known and widely used.

3.3.3.1.5 Hemodensitometry

Recent development in hemodensitometry offer promise as a means of measuring peripherial blood flow. This is discussed under oximetry below. (Section 3.4.5).

3.3.3.1.6 Recommendation

We recommend that the transcutaneous Doppler shift technique be incorporated in IMBLMS for the measurement of blood flow in association with other cardiovascular techniques and procedures. The method is adaptable for a wide variety of blood flow measurements (see below) and can be used with a minimum of training by the crew. Recent studies by Davis and Hart (manuscript accepted for publication in Circulation Research) indicates a reasonable correlation with dye dilution techniques. Although the technique is new, we believe it to have development promise within the present IMBLMS flight schedule.

3.3.3.2 Technique Selected and Rationale

Because the transducer can be sized and shaped in an almost unlimited number of configurations, several transducer systems will be provided to meet the variety of requirements both here and as described in Section 3.3.5.

3.3.4 ARTERIAL BLOOD PRESSURE

3.3.4.1 Recommendation and Rationale

For measurement of arterial blood pressure we recommend the standard technique of using an occulsive cuff and observing the Karotkoff sounds over the brachial artery. For this latter purpose a microphone is sewn into the cuff so that proper positioning is assured. The microphone can be the standard GFE model or any similar one with a flat frequency response up to 100 Hz.

3.3.4.2 Technique Selected and Rationale

Provisions have been made for automatic cuff inflation using the present GFE system. Such a system is desirable particularly in association with the bicycle ergometer experiment.

As a modification from previously used systems, we recommend a device developed by Smith Kline Instrument Company. The unit is designed to "listen" electronically for the first and last Karotkoff sounds and to present systolic and diastolic pressure as specific electrical analogues offering considerable simplification in crew training requirements.

3.3.5 BLOOD FLOW

3.3.5.1 Recommendation and Rationale

A thorough study of the possible use of Doppler ultrasonic techniques for blood flow (as developed by Dr. Robert Rushmer, University of Washington) has convinced us that measurements in this area can be much expanded. The safety and ease of use plus the valuable information obtainable with these techniques leads us to recommend this system for IMBLMS.

3.3.5.2 Technique Selected and Rationale

3.3.5.2.1 Thoracic Blood Flow

This measurement has been shown by both animal and human experiment to correspond very closely to cardiac output as measured by dye dilution techniques (Davis & Hart, manuscript accepted for publication by Circulation Research). The technique involves only the observer (or subject) placing the transducer over the thoracic aorta (left lung lower apex area) for a period long enough for the system to record a short series of cardiac output complexes.

3.3.5.2.2 Regional Blood Flow

We recommend the same techniques for use in assessing regional blood flow under a variety of conditions. Separate transducers will be provided when regions of interest are established. It can be used during studies of inflight exercise (3.3.7), lower body negative pressure (3.3.9), ballistocardiography (3.3.11), and others. The ease and conditions of use are as described above with the only difference being the placement of the transducer.

3.3.5.2.3 Arterial Flow Pulse Contour

The Doppler system records the arterial velocity pulse contour of whatever artery over which it is applied. Given only a small change in blood vessel diameter, it is this contour which constitutes the input allowing the automatic processing of cardiac output and flow. The pulse contour is measurable by this technique over the entire range of arteries from the thoracic aorta to the pedal, volar, and opthalmic.

3.3.5.2.4 Arterialor Reactivity

Arteriolor reactivity can be followed under almost any circumstances by Doppler observation of the small artery flow characteristics in the limb or areas of concern. Without invasive techniques deep arterialor reactivity measurements are inaccessible to IMBLMS.

3.3.6 PERIPHERAL VENOUSE PRESSURE

For methods of measurement of peripheral venous pressure a major study has been conducted by GE (as reflected in the earlier Phase B final report, Section 3.4.1.6 and Tables 3-3 and 3-4). During Phase B-II this study has continued and has now resulted in the single recommendation for a very simple, yet accurate device developed by Biosystems Inc. It is small and light, totally mechanical, easy to read and requires almost no training for use. A summary of most of the systems considered is shown in item No. 12 of Table 3.3-1. The plethsymograph has been considered of less importance because of its complications and variable results. Pulse wave considerations are discussed under Section 3.3.5 in the review of Doppler capabilities available. Thermography has been ruled out. Venous compliance has been treated separately under Section 3.3.10.

3.3.7 IN FLIGHT EXERCISE

3.3.7.1 Recommendation and Rationale

The measurement of in flight exercise per the bicycle ergometer is incorporated in IMBLMS as GFE as either a cardiovascular, respiratory or metabolic stress procedure places on IMBLMS straight forward support and service requirements. Provisions have been made to record RPM and watt-hours during periods of ergometer use. It is presumed that while a subject is on the ergometer, many of the cardiovascular and respiratory measurements discussed elsewhere can and will be made.

3.3.7.2 Technique Selected and Rationale

A bicycle ergometer experiment has been developed and used to assess data management loads (section 3.4). We are aware of the whole body exerciser under development at AMD and believe that IMBLMS contains all the support and services functions required for this device.

Table 3.3-1. Venous Pressure Measurement Methods

1.	Air Displacement Plethysmograph
2.	Water Displacement Plethysmograph
3.	Capacitance Displacement Plethysmograph
4.	Impedance Displacement Plethysmograph
5.	Photoplethysmography
6.	Circumference Measurement
7.	Thermal Flow
8.	Doppler Shift
9.	Pulse Wave Velocity
10.	P-A Delay
11.	Standing Wave Resonance
12.	Superficial Vein Pressure Chamber Balance
13.	Ocular Method
14.	Peripheral "A" Wave Detector
15.	Venous Run-off
16.	Thermography

3.3.8 RHEOLOGY

Rheology, or the study of flow characteristics by impedence techniques, adds another parameter to our recommended measurement list for the cardiovascular system. It is simple and safe and utilizes much of the same equipment as called for in other measurement descriptions. While having a much longer history of clinical use however, it is presently not as sensitive a technique as the Doppler recommended above (3.3.5).

This technique is being suggested for use in IMBLMS on both upper and lower extremities. Electrodes will already be available in the proper locations for other purposes (such as electromyography 3.5.4).

3.3.9 LBNP

The lower body negative pressure technique is a means to rather than a specific physiological measurement. The actual measurements of the LBNP unit will be simply a recording of pressure in relation to time. At the same time however, it is assumed that most of the cardiovascular measurements will be made during such exposure either singly or in some combination. Arrangements are recommended therefore for regional blood flow (3.3.5.2) and venous compliance (3.3.10) to be made by properly placing the necessary sensors inside the the LBNP suit in locations as described in the specific measurements sections mentioned above.

3.3.10 VENOUS COMPLIANCE

3.3.10.1 Recommendation and Rationale

Venous compliance is one of the very important measurements of the cardiovascular system during space flight. The $\Delta p / \Delta V$ relationship may be a very valuable indicator of the tonous of the venous bed. Because of its possible significance, it is unfortunate that the technique is awkward and the data variable.

3.3.10.2 Technique Selection and Rationale

The recommended technique involves placing a strain gauge around one lower limb and exposing that limb to lower body negative pressure while measuring $\Delta p / \Delta V$. The strain gauge is the same as that suggested for certain respiratory measurements. Alternate techniques which have been considered include the Whitney gauge (using an electrolyte rather than mercury) and the capacitance cage. Although development is proceding on the latter our evaluation of its present state has led to its omission.

3.3.11 BALLISTOCARDIOGRAM

Ballistocardiography under conditions of zero G forces might prove to be one of the most interesting of the cardiovascular measurements. Various configurations have been studied with all leading to the same conclusion. The size, shape, and complexity of the equipment (GFE) plus the immense data processing load necessary to accumulate and to assess mean-

ingful data however lead us to the conclusion that while IMBLMS as we conceive it can accommadate this measurement, it should not be recommended as a regular part of the system, but rather as a separate experiment.

3.3.12 CARDIOVASCULAR MEASUREMENTS NOT RECOMMENDED

3.3.12.1 Carotid Body/Sinus Stimulation

This measurement, if not performed under very carefully controlled conditions by highly skilled medical personnel, could be very dangerous, particularly if weightlessness leads to a significant and untoward adaptation of these reflexes.

3.3.12.2 Elastic Leotard

Elastic leotards which satisfy MSC-A-D-66-3 are not currently available and the device in its current form cannot be recommended.

3.3.12.3 Central Venous Pressure

No non-invasive method central venous pressure has been identified. Although a sterile venous catheter can be provided in IMBLMS, it is not recommended.

3.4 RESPIRATORY MEASUREMENTS

Design requirements were formulated for two basic types of gas measuring systems:

a. A rapid response system for breath by breath analyses and single breath techniques.

b. A slow response system with a rebreather for accurate measurement of O_2 consumption and for other closed circuit measurement.

The least satisfactory equipment area in pulmonary studies has been mass flow measurement. A Dual Turbine Flowmeter developed for cryogenic measurements and other fluids, by Quantum Dynamics and only recently modified for physiological use, appears to have solved this problem. Gas partial pressures may adequately be measured by a mass spectrometer. Using appropriate sample line lengths to minimize phase relation problems, these equipments will provide accurate readings for the worst case, breath by breath analyses.

Although the Quantum Dynamics Flowmeter appears most promising, a new flowmeter developed by Donti Research Development Company is being investigated. These instruments were clinically evaluated at Montafiore Hospital in New York City. Both of these devices exhibit greater accuracy than presently used instruments such as the Technology Incorporated Mass Flowmeter.

With the addition of an ear, forhead, or nares oximeter (Section 3.4.5) and a flow interrupter, and by judicious pneumatic design, IMBLMS offers a very effective means of studying pulmonary function.

3.4.1 RESPIRATION RATE

There are two methods of determining respiration rate. If the test subject is instrumented for other respiratory measurements involving the mass flowmeter, respiration rate may be directly calculated from the flowmeter output. Otherwise, a strain gauge may be incorporated into an electric chest band which is worn by the subject. This method provides none of the inconveniences of a self-heated thermistor inserted in the nares. Differences in nasal and oral breathing could have major effects on this type of measurement. The conditioned strain

gauge signal is of the same general waveform as the flowmeter output, and an identical pneumotachometer data handling process is used in the data management equipment.

3.4.2 LUNG VOLUMES

With the incorporation of a very accurate flowmeter, such as the Quantum Dynamics or Donti devices described in Section 3.4, the measurement of lung volumes becomes very simple. The test subject breathes in a predescribed manner, and the flowmeter output (which is bi-directional) is integrated. Residual volume, which cannot be measured in this manner, is determined by use of the Helium rebreathing method (described under Ventilation 3.4.7).

3.4.3 PRESSURE, FLOW AND VOLUME

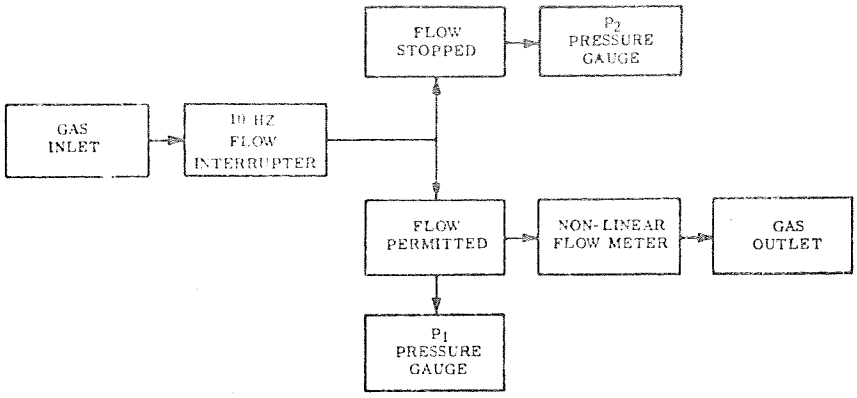
The most difficult obstacle in the performance of this measurement is measuring the intrapleural to mouth pressure gradient. Since esophageal balloon techniques have been eliminated as a part of IMBLMS, an alternate technique is required for determination of relative intrapleural pressure. A promising technique for this measurement is shown in Figure 3.4-1. In this technique, respiratory flow is chopped in an on-off manner at a rate of 19 Hz. When flow is blocked, it is assumed that pressure at the mouth becomes equal to intrapleural pressure. Flow is obtained directly from the flowmeter (para. 3.4.2) and is integrated to determine volume. Therefore, pressure and flow relationships (airway resistance) may be determined as a function of lung volume. This measurement may be made for both inhalation and exhalation.

3.4.4 BREATH BY BREATH RESPIRATORY ANALYSIS

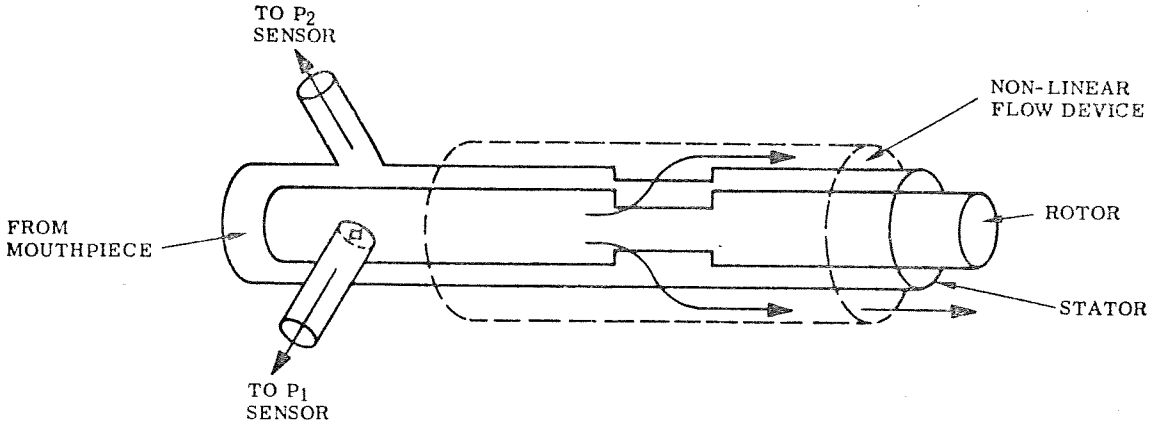
The breath by breath measurement of O_2 consumption and CO_2 production can be made with a mass spectrometer figure and flowmeter (section 3.4.2, 3.4.3) in line. The governing equation for these measurements is:

$$(1) \qquad O_2 \text{ cons.} = \int \text{FLOW}_{\text{insp}}\, p^{O_2}\, dt - \int \text{FLOW}_{\text{exp}}\, p^{O_2}\, dt$$

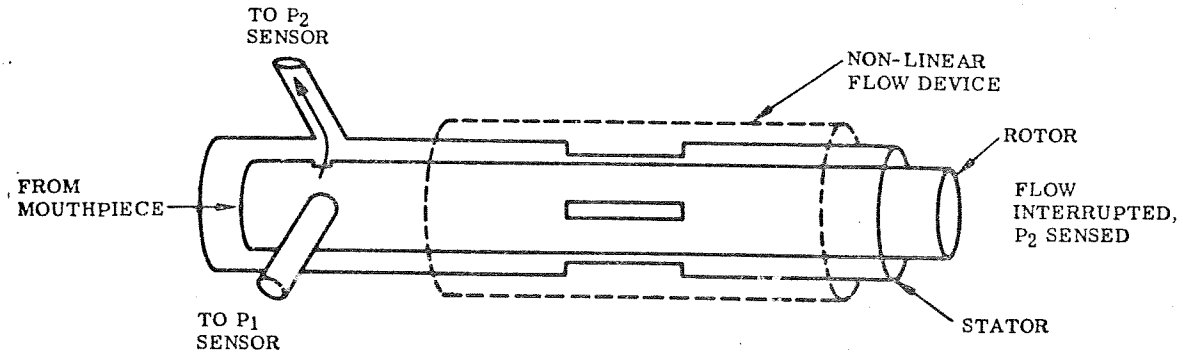
$$(2) \qquad CO_2 \text{ prod.} = \int \text{FLOW}_{\text{exp}}\, p^{CO_2}\, dt - \int \text{FLOW}_{\text{insp}}\, p^{CO_2\ \text{insp}}\, dt$$



A. Interrupter Function Flow Diagram



B. Interrupter: Gas Flow Permitted



C. Interrupter: Gas Flow Interrupted

Figure 3.4-1. Interrupter

From these equations it can be seen that the phase relationships between flow and partial pressures are very important, and must be optimized. Such an approach is designed into our overall IMBLMS data handling system.

3.4.5 ALEVOLAR TO ARTERIAL O_2 GRADIENT

The ear, nares, finger or forehand oximeter is a non-invasive device for evaluating the oxy-hemoglobin status of blood. It is painless, convenient, and has been widely used. It is expected that the major problem in oximetry, i.e. errors in calibration and difficulty in determining absolute values, will be soon improved.

Almost all oximeters available to date have suffered the problem of the inherent errors due to problems of measuring transmitted light through blood in tissue (a non-newtonian liquid subject to Reyleigh's law concerning light scattering). While recognizing this, we believe that the best instrument for this purpose is the nares oximeter (a transmission device). Unlike any of the other (including reflective), it is totally independent of skin thickness, coloration, etc. In addition, it has the valuable added feature of reading O_2 saturation from the internal carotid artery (the only anatomical spot where this can be conveniently done).

The alveolar O_2 measurement will be made by considering the mass spectrometer observing at end-expiration.

3.4.6 O_2 CONSUMPTION

The breath-to-breath analysis of O_2 consumption contains several inherent errors. Therefore, for a steady-state measure of O_2 consumption, this technique is inappropriate. However, the rebreather to be used for the Indirect Fick determination of cardiac output, Ventilations, and Diffusion measurements may easily be instrumented to measure O_2 consumption.

If a non-soluable diluent gas such as N_2 or H_e is used in the rebreather, and if all CO_2 is removed from this system, the oxygen added to the rebreather to maintain a constant pO_2

is equal to the metabolically consumed oxygen. Such a measurement is quite accurate over a period of several minutes.

3.4.7 VENTILATION

In order to study pulmonary ventilation, a Helium rebreathing method is recommended. By studying the rate of Helium partial pressure decrease, ventilation is determined. The final or steady-state of Helium concentration also provides a measure of Residual Lung Volume.

As an ancillary to this technique, evenness of ventilation may be studied by the single breath nitrogen measurement. This requires only an adaptor to the oxygen supply and the mass spectrometer (see Figures 3.4-2 and 3.4-3) both of which are IMBLMS equipments. This measurement is less quantitative and accurate than the helium technique, and should be performed only if required.

An alternate approach being investigated in the "VELOCITY VOLUME LOOP" technique described by Dr. Roscoe G. Bartlett in his paper: Pulmonary Evaluation in Air & Space Flight. Industrial Medicine and Surgery, 32:1, 2-8, January 1963.

Ventilation studies by the O_2^{18} method have been discussed with Dr. Richard W. Hyde (Penna. University) but are not recommended because of their complexity and the unusual equipment necessary, and the fact that this technique is considered by respiratory physiologists to be at best only a research technique.

3.4.8 DIFFUSION

The recommended technique for diffusion measurement is the Carbon Monoxide rebreathing method. The greatest difficulty in performing this measurement is monitoring carbon monoxide partial pressure, because CO and N_2 interfere on the Mass Spectrometer. Therefore, a special purpose CO sensor is required.

A convenient and accurate solution to this problem is presently being developed at GE. In this technique, the gas sample containing CO is passed through a reactor containing Mercury Oxide at 200°C. Free Mercury and Carbon Dioxide are liberated and pass through a mass spectrometer before being dumped overboard. Mercury Vapor partial pressure will then give an accurate determination of CO partial pressure.

Diffusion is a very important measurement, especially in the light of the use of the indirect Fick Method for determining Cardiac Output.

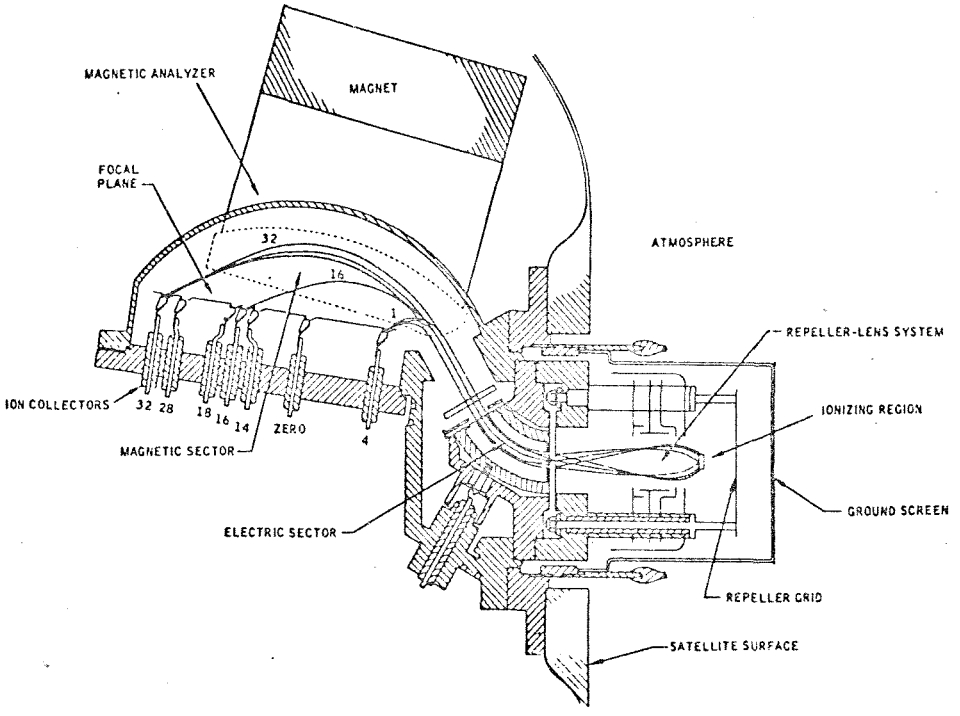


Figure 3.4-2. Mass Spectrometer Configuration and Ion Path in X-Y Plane

Figure 3.4-3. Perkin-Elmer Magnetic Sector Mass Spectrometer

3.4.9 ARTERIAL O_2 SATURATION

This measurement has been described in section 3.3.5, alveolar to arterial O_2 gradient.

3.5 METABOLISM AND NUTRITION

The measure of metabolism and nutrition consisting of such things as core temperature, body mass, muscle size, muscle strength and electromyogram are direct measurements which added to the derived energy metabolism measurement (3.5.5) complete the requirements as evolved during our study to present a useful description of what occurs metabolically in a closed ecological system at zero G.

The measurements suggested also are compatible with monitoring the crew's safety from the standpoint of ability to adequately utilize the food intake, also assessment of maintenance of muscle tone and coordination required to perform the assigned tasks for operation of the flight.

Core temperature is utilized as well in the performance of cardiovascular measurements and indeed is integral to the proper interpretation of their results. It should be noted that this is as well as overall metabolic measurements are intimately related to measures described under the titles of physiology (3.3), respiration (3.4), neurology (3.2), and behavioral (5.0).

3.5.1 CORE TEMPERATURE

The core temperature technique was evaluated in comparison with a thermistor harness providing skin temperatures from twelve sites, an oral temperature thermistor to be used in conjunction with (or in lieu of it), and an anal thermometer.

The core temperature procedure is our choice of method since our study revealed that great variation gradients exist using the thermistor harness both from subject and also on the same subject at varying times under the same conditions. This last problem appears to be a function of the ability of the subject to replace the harness and subsequently hit the same contact points (as well as certain problems with regional blood flow differences). The oral

unit has also been discarded for the following reasons. First and foremost the insertion and holding of the thermistor in the oral cavity will grossly interfere with such things as relieving thirst, talking or expressing breath orally without affecting the temperature readings obtained. Second and of considerably less importance the esthetics of the oral thermistor have in the past presented a problem. Another consideration which can be handled in the training program but may not be adhered to in flight is the application of disinfectants to the thermistors before each insertion.

The anal thermometer is also unrealistic due to variations in fecal mass, esthetics and the difficulties of acceptability to the subject.

The core temperature thermistor used will be individually modeled to fit the astronaut. Past experience has shown it to be a reliable gauge of core temperature, having a high degree or precision. The reproducibility of temperature changes due to stress, exercise or fever producing conditions is excellent.

3.5.2 BODY MASS

No conflicts arise as to the need for this measurement which is basic to the study of nutrition and metabolism.

The GFE Body Mass Measurement Device (BMMD) currently being developed by AMD for NASA will be utilized for this measurement. The BMMD works on the principle of the periodicity of a pendulum e.g. simple harmonic motion, in which the period of the oscillation is a proportion of the square root of the body mass. The device as conceived measures a total period of 3 cycles oscillation of mass scale by a 6 decade digital timer to an accuracy of 10^{-5} seconds. The prototype unit measured 50 to 1000 gm masses with an anticipated accuracy of .03% of the measured time. Calibration will be only to 0.1%. It is anticipated however that the operational unit will operate in a range from less than 50 gms to greater than 200 kilograms. The anticipated accuracy and calibration figures as given above reflect estimates based on ground testing, however a more realistic appraisal would indicate an accuracy of just under 5% under flight conditions.

3.5.3 MUSCLE SIZE AND STRENGTH

The measurement of muscle size and strength, though relatively simple to perform, gives information of great import when evaluations of the effects of zero gravity are to be made. Any change or reduction in muscle size or strength can seriously impede the subject in his normal activities, in the operation of the space vehicle, also in the performance of some tasks required such as those which utilize the ergometer or dynamometer.

The measurement of muscle size is easily accomplished with the aid of tape measures and/or calipers.

Echo-sounding ultrasonic measurement techniques have been carefully considered as a potential alternate for measurement of either muscle or organ size. This type of instrumentation offers much promise for the future; however for IMBLMS it is not now recommended because of the extra instrumentation currently required. Such procedures are considered as excellent candidates for inclusion in later expanded versions of the system.

Measurement of strength is recommended with a zero reaction dynamometer used in the subject's hand. It is recommended that such a hand grip dynamometer be used as a measure of upper-body strength. For leg strength, the bicycle ergometer pedals can be locked and instrumented with strain gauge to measure force applied. We recommend this technique because the technique is simple and straightforward and the equipment is already available aboard.

3.5.4 EMG

The electromyogram is an excellent measurement of muscle tone, and is a valuable tool in studying the effects of prolonged weightlessness on the muscle system.

It is recommended that the EMG be performed with electrodes attached preflight to the arm (biceps) and leg (calf). The measurement was analyzed, and it was determine that an upper frequency limit of 100 Hz would be used for the EMG. This choice permitted use of VCG signal conditioners, and prevented an undue load on the Data Management System. IMBLMS is also prepared to offer an integrated EMG signal if desired. Some consideration was also given to the handling of the EMG amplitude and frequency envelopes. These envelopes give an indication of the number of spike potentials per unit time. For accuracy and ease of data handling this technique merits future investigation.

3.5.5 ENERGY METABOLISM

This measurement is to be taken both on the bicycle ergometer and while the subject is performing specified maintenance tasks. The latter will be performed under both pressure suit and shirt sleeve conditions. Energy Metabolism is measured breath by breath, as in Section 3.3.4.

On the ergometer, RPM and watts output will be measured. For the maintenance task, time tags for various task performances must be recorded. As an adjunct to the behavioral area, cinematography will be employed as a measure of task performance.

SECTION 4

LABORATORY ANALYSES

4.1 SUMMARY

Those measurements pertaining to Biochemistry, Hematology, Cytology, Microbiology and Immunology have been re-evaluated in the light of two major ground rules:

a. First flight date is mid-1971.

b. On all IMBLMS flights one member of the crew will be a physician, physiologist, or "medically trained" astronaut.

The first ground-rule allows more lead time for development of hardware and techniques for on-board use. Thus, more hematological and biochemical measures can be done on-board than with a mid-1970 flight. On-board leucocyte culture still poses a problem, but in-flight procedures are possible within the new schedule. Some immunological and microbiological procedures could be developed for on-board use with the added lead-time, but the extent to which these procedures can be incorporated into an on-board regimen is largely dependent upon the ground-based studies needed to define specific measurements of interest. Therefore, only sample return is recommended for microbiological and immunological measurements.

Although the guaranteed presence of an astronaut physician or biological scientist would aid in making more measurements feasible for on-board performance, the added lead-time can be put to profitable use in training the candidates for IMBLMS flights in the procedures required for on-board analyses.

Each measurement on the selected list, as modified by NASA, has been evaluated for possible inclusion in IMBLMS by the following criteria in an on-board vs post-flight tradeoff analysis:

a. Safety

b. Physiological Significance

c. Complexity

d. Skill/Training Requirements

e. Lead-time needed for development of On-Board Methods and Hardware.

Implicit in this evaluation was that those procedures which are sensitive, precise and accurate were sought for on-board performance.

Equipment which supports a number of analyses has been stressed, with single-use devices kept to a minimum. A centrifuge, a microscope, and a controlled temperature storage capability can be used to support a variety of experiments. The addition of a spectrophotometer/densitometer and a radioisotope sensor greatly broadens the on-board analytical capability. Development will be required if ground equipment design is to be modified for in-flight use. Currently available hardware, as well as concepts in various stages of development for automation of biochemical analyses, have been considered for possible application to IMBLMS. All commercially available devices are found unsuitable for IMBLMS use. However, a research and development effort* sponsored by GE is in progress in this area which may well result in hardware applicable to IMBLMS.

Modifications of existing biochemical techniques by simplifying wet chemistries or devising "dry" methods have been evaluated. If an appropriate R&D effort is funded on a timely basis, a sizeable array of analyses will become available for IMBLMS.

With the establishment of the measurement schedule list, attention was turned to the measurement frequency schedule. Measurement frequency is governed by a number of

*The vendor is not working under this contract thus the Rights to Data clause of this contract does not apply.

factors, i.e., volume of sample, time to perform the measurement, expendables needed, equipment required, return sample weight and volume, and most important, data requirements.

Since the worth of a measurement is governed solely by the quality of the data obtained from it, each measurement must have the attributes of sensitivity, precision and accuracy. New or modified techniques and methods as well as the new or redesigned hardware and ancillary expendables needed to use these procedures must be thoroughly tested by both skilled technicians in the laboratory and by crew members themselves during simulated flights on the ground. Such testing can be included as part of the control studies which are a sine qua non of every experiment worthy of the name.

The IMBLMS Program offers an exciting opportunity to perform well-designed experiments, supported by sound measurement techniques, in an environment which has unknown effects on the biology of man. The recommendations in this section are directed towards the realization of the opportunity.

4.2 MEASUREMENT SELECTION CONSIDERATIONS

Both automatic and manual measurements were evaluated for IMBLMS use in the light of the NASA measurement list. Other measurements which have been previously considered for use on IMBLMS were also evaluated, but it was felt that there were few if any additions required for the NASA list. Rather, the list was looked at with a view to reducing it in size until it was compatible with the limitations imposed by IMBLMS, but would still retain all measurements necessary to define the changes occurring in the physiology and biochemistry of the astronauts during an extended flight. Methods were evaluated for application by considering not only physiological significance but also complexity, crew skills and lead-time required to flight qualify the methods and associated hardware, in an on-board vs. post-flight trade-off. During this trade-off, the NASA measurement list was scrubbed down and a number of measurements omitted from further consideration during this study. With the measurements to be made determined and the volumes of biological fluids required, plus the amounts of expendables needed in addition to equipment requirements defined, the frequency of measurement was considered in terms of the effects of this frequency upon astronaut health, experimental design, R&D requirements and data quality. A rationale for the performance on-board, the preservation of a sample for post-flight analysis or the omission of a measurement is given in this section.

4.2.1 AUTOMATED VS. MANUAL MEASUREMENTS

Currently available hardware, as well as concepts in various stages of development for automation of hemotological and biochemical techniques have been considered for possible application to IMBLMS. No commercial instrument lends itself to OWS use without a virtually complete redesign. A promising development, though, in the automated wet chemical analysis area is now in the breadboard fabrication stage and is being funded by General Electric. (The vendor is not funded under this contract and therefore the Rights and Data clause of this contract does not apply.) This device also is planned to have an automatic cell counting capability.

4.2.1.1 Automatic Analyses

Automatic wet chemical analyzers which have been evaluated for possible use on IMBLMS are:

a. Autotechnicon - Technicon, Inc.

b. Robot Chemist - Warner Chilkott

c. Mark X - Hy-Cel, Inc.

d. Clino-Mak - Mark II - Lab Line

These devices are all currently on the market, with the Auto-Technicon being the most widely used piece of equipment. A device quite similar to the Robot Chemist is being developed by Dade Reagents, Inc. None of these systems is directly applicable to IMBLMS because they have been developed for the clinical laboratory which handles hundreds or thousands of a limited number of different wet chemistries each day. IMBLMS requires a few of each of many different tests. Furthermore, the standards of precision, accuracy and sensitivity which are required for IMBLMS experiments are not usually found in a clinical laboratory and the instrumentation, therefore, is not designed to specs as tight as those required for research equipment. For example, comments from a number of users indicate that the precision of the Auto-Technicon is approximately $\pm 15\%$.

A method, which also may be included under the heading of automatic, is that devised by Dr. Samuel Natelson of the Michael Reese Hospital in Chicago. He has developed, under NASA Contract, a method using paper tapes (which may present a fire hazard) impregnated with the necessary reagents for colorimetric determinations. The advantage of Natelson's system for the clinical laboratory is that no reagents are required. They are all contained in the tapes. This, too, would be an advantage within the confines of a space vehicle. However, the tapes as presently used in Natelson's laboratory are so devised that a roll of tape contains the capacity for doing several hundred tests of the same kind, e.g., glucose. It would be possible to arrange in sequence two, three, five or more different tests on Natelson's tapes, but even if the sequence were very carefully marked, there would still be

too much of a chance for operator error. The principle of Natelson's methodology is that whole blood, serum, plasma, or urine can be placed upon filter paper discs which are mounted on a selectively permeable membrane tape of mylar, cellophane, or micro-pore which is, in turn, backed by a filter paper tape impregnated with the reagents required for a specific test. The membrane pore size controls the passage of the blood constituents from the disc where the sample has been placed, to the chemically treated paper. The latter is dried and heated for color development and then run through a densitometer. This arrangement is excellent for repetitive samples — for example, the hospital laboratory where one hundred or a thousand of the same tests are to be run each day. However, for an IMBLMS day, a number of different tests may be done on each given sample of blood, serum, plasma or urine. Thus a series of several discs would have to be placed in sequence with the limiting factor being the pore size of the membrane chosen for backing the filter paper discs upon which the samples are placed. Another version of Natelson's approach is discussed under Manual Methods.

NASA Tech Brief 66-10515, JPL Invention Report 30-962, Apparatus Enables Automatic Microanalysis of Body Fluids, was reviewed and the analysis unit discussed with JPL personnel. It was designed for the 30-day Biosatellite, but the analysis unit has not yet functioned for 30 consecutive days. No information on precision or accuracy is available. The device was of interest because of the small sample volumes used (ultramicro range) but the tolerances on the moving parts are so small, that it is doubtful, with the present design, that the accuracy of sample and reagent measurement can be maintained over a period of 60 days with a high usage rate. Of note also, is the statement made by an official of a company which is a potential subcontractor on IMBLMS that the JPL analysis unit infringes on previous patents filed by him.

Undergoing development at the present time in the Bioastronautics Laboratories of the General Electric Company, is a device which will perform a wide range of wet chemistries. The initial breadboard will be able to perform two simple colorimetric tests, total hemoglobin and the biuret reaction for total protein. At later points in the development cycle, capability for making the following measurements will be added: Sodium, Potassium,

Chloride, Calcium, Magnesium, Phosphate, Glucose, BUN, Alkaline phosphatase, CPK, LDH, SGOT, SGPT, as well as red and white cell counting. With the present design, it is anticipated that the precision will be within ±3% and the accuracy within ±5%.

4.2.1.2 Manual Methods

Natelson's approach has been discussed under paragraph 4.2.1.1. However, a manual method using his paper tapes would consist of making up tapes of approximately band-aid size with a different band-aid for each test. Thus, each piece of tape could contain both standards and filter paper discs upon which a sample could be placed. For example, for blood glucose, standards of 50, 100, and 150 milligrams percent plus six test spots (two each for the three crew members) could be contained. The test samples would be placed on the appropriate discs, the filter paper pressed, heated for color development, and then read by densitometry. Although densitometry is not the most accurate of methods, Natelson claims that his present accuracy and precision of ±10% can be greatly bettered. One possible improvement which may be of merit, would be to use cellulose acetate strips which, when properly cleared become transparent and allow more accurate measurement of color development, as in electrophoresis. Natelson now can do glucose, urea and protein on whole blood, and also can do urine ammonia. The number of tests that can be developed is a function of funding.

A number of conventional methods have been evaluated, both for hematology and biochemistry. In the hematological area, the only automatic method readily available would be cell counting. It is possible that within the next few years, hematocrit and red cell mass may also be done automatically, but these developments are long lead-time items.

Conventional wet chemistries have, in many cases, been simplified to the point where unskilled technicians can be trained to use these methods and obtain results suitable for the clinical laboratory. Among those companies surveyed who purvey kits, pre-mixed reagents and the equipment with which to use them, are Smith, Kline Instrument, Dade Reagents, Hy-Cel, Inc., Harleco, and Ames. The Dip Stix made by Ames, and similar products made by several of their competitors, do have a use for IMBLMS, specifically for the on-board, routine urinalysis. These chemically treated strips which change color roughly in

proportion to the presence of a given constituent are gross tests which aid in assessing whether or not a given individual is within the "normal" range or not. However, since IMBLMS is not an orbiting hospital or doctor's office, the rest of the measurements which are to be made on the crew members during IMBLMS missions, must be performed with methods which will give results of $\pm 5\%$ precision and accuracy at the worst.

The Eskalab Clinical Chemistry System manufactured by Smith, Kline Instrument Co., a division of Smith, Kline and French Laboratories, consists of pre-measured reagent tablets (only one per test), a disposable cuvette assembly, and a spectrophotometer. Using self-filling micropipettes, several determinations can be run on a single blood sample. The largest sample required for any test is 50 microliters. Most use smaller samples. Pre-filled diluent reservoirs are supplied with the correct amount of fluid required for each test. An adapter connects this reservoir to a clear plastic disposable cuvette. The technique used for all tests is as follows: a reagent tablet is placed in the cuvette, the adaptor is then attached. Next, the diluent reservoir is connected to the adapter and the assembly is inverted to dissolve the tablet. A micropipette is used to add the proper sample volume to this mixture. After color development, the absorbance of the mixture is measured in the spectrophotometer and the disposables are discarded. This system holds promise for possible use on IMBLMS, but requires considerable development and at present is limited to seven tests, with others scheduled for release to the commercial market in 1968 and 1969.

Discussions have been held with both Dade Reagents and Harleco which are subsidiaries of American Hospital Supply Company, Inc. and the estimate made by a joint team from these two companies indicates that approximately one to two years of development is required for a reasonable complement of biochemical tests. Smith, Kline Instruments, Dade and Harleco are all interested in developing tests based on pre-packaged reagents with the goal, in many cases already realized, of one reagent capsule or pellet per test.

The most probable combination of onboard measurements, based upon our evaluations to date, would appear to be a combination of certain Natelson's tape methods, plus a limited number of wet chemistries as indicated in Section 4.2.2.1. However, it must be emphasized

that considerable ground testing is required in order to make the tests available in a form which meets the ground rules laid down by NASA for materials permitted on-board spacecraft. Furthermore, modification of the expendables, such as cuvettes, is essential because of the behavior of liquids in zero-g. It is also assumed that concurrent with the development of wet chemical methods, the necessary hardware will also be developed. There is little time for delay, because a two-year lead time estimated for flight qualification of an array of methods plus the hardware and expendables necessary to perform them does not include the procurement cycle. The two years is estimated from the first working day of the contract. Therefore, any delay in initiating R&D for development of new and modification of existing techniques will decrease the number of tests available for IMBLMS.

A major benefit derived from simplified manual methods is that automation of a test requiring addition of only one reagent to the sample is much simpler than automating a test using three or four reagents.

Simplified manual tests, then, are available which can be used for analyses of on-board IMBLMS if R&D funding is forthcoming for development of techniques and flight qualified hardware and expendables.

Tables 4.2-1 and 4.2-2 group blood and urine measurements by the volume required for a single assay. The total volumes (worst case) which will be required from each astronaut over a 60-day period are depicted graphically in Figures 4.2-1 and 4.2-2, using the same groupings.

TABLE 4.2-1. BLOOD MEASUREMENTS-GROUPING BY VOLUME OF BLOOD SAMPLE REQUIRED FOR A SINGLE ASSAY

0 - 1 ML BLOOD	ML
Total Protein	1
Hemoglobin (On-Board)	0.5 - 2
Fibrinogen	0.2 - 2
ACTH	1
RBC Mass (On-Board)	1
Protein Electrophoresis	0.0006
RBC Survival (On-Board)	1
Total Body Water	1
Blood Cell Morphology (On-Board)	0.1
RBC (Total) (On-Board)	0.1
WBC (Total) (On-Board)	0.1
WBC Differential (On-Board)	0.1
Platelet Estimate (Smear) (On-Board)	0.1
Reticulocyte Count (On-Board)	0.1
Hematocrit (On-Board)	0.5
Bleeding Time (On-Board) No Collection	------
Clotting Time (On-Board)	0.5 - 1
Bilirubin	0.2 - 0.4
LDH	0.2
LDH Isoenzymes	0.2
SGOT	0.4
SGPT	0.4
PBI	0.05
Prothrombin Consumption	0.4 - 6
Transferrins	1-2
Calcium	0.2 -1
Phosphate	0.2 - 0.4
Cholesterol	0.2 - 2

TABLE 4.2-1. BLOOD MEASUREMENTS - GROUPING BY VOLUME OF BLOOD SAMPLE REQUIRED FOR A SINGLE ASSAY (Cont)

0 - 1 ML BLOOD	ML
BUN	0.2 - 0.6
Uric Acid	0.4 - 0.8
Alkaline Phisphatase	0.2 - 0.8
CPK	0.4
Immunoglobulins	1
Complement Titration	1
Antibody Titration	1
Parathyroid Hormone	0.5
1 - 5 ML BLOOD	
Lymphocyte Karyotyping (On-Board)	2.5 - 5
Plasma Volume (On-Board)	2
Free Thyroxine (T_4)	4-6
Fibrinolytic Activity	3
Blood Lipids	4
> 5 ML BLOOD	
Electrolytes	6 - 10
Calcitonin	50
Mineral Metabolism by Isotopic Techniques	10

TABLE 4.2-2. URINE MEASUREMENTS - GROUPING BY VOLUME OF URINE SAMPLE REQUIRED FOR A SINGLE ASSAY

0 - 1 ML URINE	ML
Osmolality (On-Board)	1
Color (On-Board)	----
Specific Gravity (On-Board)	1
Glucose (On-Board)	1
Protein (On-Board)	0.2 - 1
Blood (On-Board)	1
Microscopic Exam (On-Board)	1
Mucoproteins	0.2
Total Amino Acids	1
ADH	0.2 - 1
Accurate Urine Volume	-----
Creatine	0.1
Creatinine	0.1 - 1
Nitrogen	0.2 - 1
Calcium	0.1 - 1
Phosphorus	0.1 - 0.5
Potassium	0.1 - 1
Chloride	0.5 - 1
Sulfate	0.1

TABLE 4.2-2. URINE MEASUREMENTS - GROUPING BY VOLUME OF URINE SAMPLE REQUIRED FOR A SINGLE ASSAY

1 - 5 ML URINE	ML
pH (On-Board)	1 - 2
Bile (On-Board)	5
Pyrophosphates	1 - 5
Hydroxyprolines	1 - 5
VMA	4
5 - HIAA	5
Magnesium	2
5 - 10 ML URINE	
17 - Hydroxycorticosteroids	10
17 - Ketosteroids	5 - 10
Catechols	5 - 10
>10 ML URINE	
Aldosterone	15
Mineral Metabolism by Isotopic Techniques	10

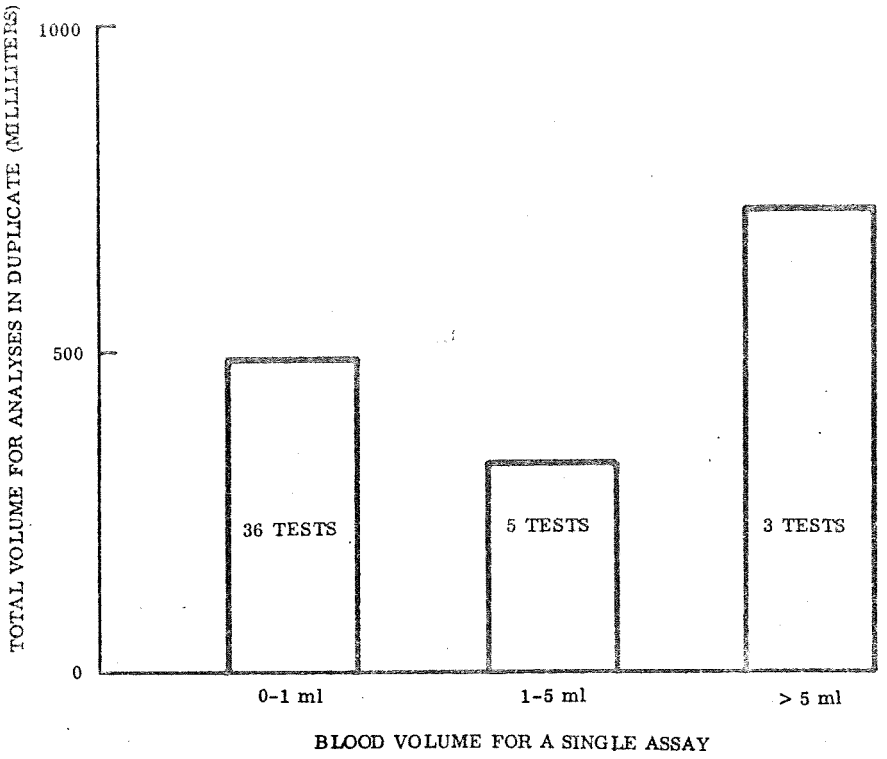


Figure 4.2-1. Total Blood Required per Astronaut for 60-Day Mission

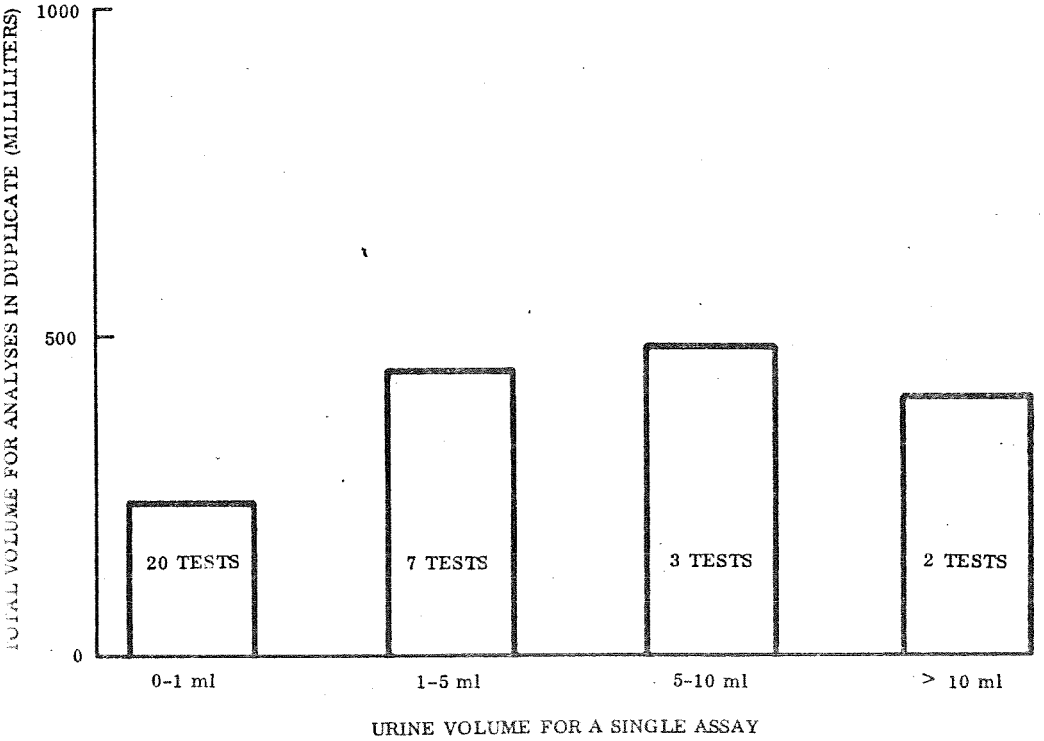


Figure 4.2-2. Total Urine Required per Astronaut for 60-Day Mission

4.2.2 ON-BOARD VS POST FLIGHT TRADEOFF

Two major variables affect the ratings obtained for each measurement. These are:

a. The skill/training/experience level of astronaut-experimenters;

b. The availability of flight qualified analytical procedures and hardware for on-board performance of in-flight analyses.

In making this trade-off, it has been assumed, therefore, that NASA will make provision for the training (lecture and laboratory) necessary to reach the skill levels required for on-board measurements and initiate appropriate procurement action so that flight prototype methods and equipment will be available for training purposes and flight-qualified methods and equipment will be available for on-board measurements

The criteria used in this trade-off, (Table 4.2-3), their definitions and the weight accorded to each criterion are discussed below.

A. Physiological Significance

10 = Most Significant
1 = Least Significant

This value judgement is concerned solely with the information regarding man's physiology to be derived from a given measurement. Most analyses accorded a significance of 10 are well documented in the biological and medical literature. Those rated a 10 for which there are few literature citations are measurements which, in the light of present theory or experience, are related to possible physiological problems in space. Since the quality of the information obtained from any measurement is a function of the analytical technique, the sensitivity, precision and accuracy of the method(s) available for making any given measurement were considered. The source of the sample was also included in assigning a rating.

B. Technical Feasibility of Performing the Analysis On-Board - As per the Phase B report, this was broken in two components, complexity and skill/training, each of which was rated separately for each measurement.

C. Complexity

8 = Least Complex
1 = Most Complex

The term, complexity, includes consideration of the number and type of manipulations, dexterity and facility required, number of pieces of equipment and time of performance.

D. Skill

6 = Least Skill/Training
1 = Most Skill/Training

Regardless of the amount of prior training and experience that a "medically trained" astronaut has had, he still will require considerable pre-flight instruction, both to refresh his memory and to become familiar with prototype flight hardware which will differ to a certain extent from common garden variety laboratory equipment. The skill/training ratings were assessed on the following bases:

6 = Idiot Proof, $<$ 10 Hours of Training
5 = 10-50 Hours of Training
4 = 50-100 Hours of Training
3 = 100-200 Hours of Training
2 = $>$ 200 Hours of Training
1 = 200 Hours of Training plus Prior Training and Experience

E. Safety of Performing the Analysis On-Board

10 = Safest
1 = Most Hazardous

The term safety encompasses the amount of volatile materials (e.g. ether) used and/or added to the S/C atmosphere, the presence and amounts of hazardous compounds (e.g. sulfuric acid, cyanide salts) used, the chemical stability of the mixtures of compounds, the handling of toxic and/or hazardous chemicals, high temperatures required in a given analysis (e.g. boiling, ashing), and the reduced pressure and possibly oxygen-enriched atmosphere of the S/C.*

F. Redundancy or Overlap

5 = Unique
1 = Redundant

This criterion is an assessment of whether or not any given measurement is unique in terms of the data obtained from that one measurement.

G. Development Lead Time

4 = 0 - 6 Months
3 = 6 - 12 Months
2 = 12 - 24 Months
1 = 24 Months

These lead times include flight qualification testing for hardware associated with any given test. The assumption made is that hardware required to make any measurement(s) on-board would be developed concurrently with analytical methods.

It is also assumed that the R&D needed, before on-board measurements can be performed, will be initiated in calendar year 1968; otherwise, the complement of on-board measurements will be reduced in number.

*For a detailed discussion of hazards, toxicity and complexity, see Final Report, Contract No. NASW 1562, pp. 3-11 to 3-40, 3-53 to 3-63, and 3-77 to 3-80 where techniques for certain measurements are described in detail. See, also, IMBLMS Phase B Final Report, Volume I, Contract NASW-1630, pp. I.3-34 to I.3-58 and I.A-49 to I.A-67 where specific methods for measurements are presented in tabular form.

In a few cases, biological problems have been encountered which are noted in the Tables (see Legend). These measurements, even though in the on-board or preserve categories, simply cannot be handled within the present state-of-the-art. They are omitted.

All other measurements with a rating of 30 or above are proposed for performance on-board, those with a rating of 12-29 are recommended for post-flight analysis on preserved samples and those with a rating of 11 or less are omitted from further consideration in this study.

Table 4.2-3. On-Board vs Post-Flight Tradeoff

Measurement	Physiological Significance/ Value 1 - 10	Technical Feasibility		Safety 1 - 10	Redundancy Or Overlap (More) (Less) 1 - 5	Development Lead Time 1 - 4	Rating	GE Recommendation On-Board, Preserve, Omit
		Complexity 1 - 8	Skill 1 - 6					
Feces								
Return of Total Dry Stool (Pi)	3	4	4	6	3	2	22	Preserve
Accurate Feces Wet weight	8	6	5	10	5	3	37	On-Board
N, Ca, P, Na, K, Cl, Mg	10	1	1	2	4	1	19	Preserve
Microbiology								
Body Microflora (Bacterial, Viral, Fungal)	10	4	1	6	5	1	27	Preserve (Cultures)
Environmental Culturing (Bacterial, Viral, Fungal)	6	4	1	7	5	1	24	Preserve (Cultures)
Sweat et al.								
Accurate Fluid Intake (OB)	10	6	6	10	5	3	40	On-Board
Sweat Measurement & Sample Return (Pi)	10	3	2	5	5	1	26	Preserve
Fluid Balance	Redundant with Accurate Fluid Intake, Feces Wet Weight, Accurate Urine Volume and Sweat Measurement							On-Board
Urine								
Routine Urinalysis (OB)*	10	3	2	9	5	2	31	On-Board*
Mucoproteins - Urine (Pi)	7	2	2	3	3	1	18	Preserve
Pyrophosphates - Urine (Pi)	6	1	2	4	3	1	17	Preserve
Hydroxyprolines - Urine (Probably Pi)	6	2	1	3	3	1	16	Preserve
Total Amino Acids - Urine (Pi)	6	3	2	5	2	1	19	Preserve
Aldosterone - Urine (Pi)	8	1	1	1	5	1	17	Preserve
ADH - Urine (Pi)	8	1	1	2	4	1	17	Preserve
17-Hydroxycorticosteroids - Urine (Pi)	10	1	1	2	5	1	20	Preserve
17-Ketosteroids - Urine (Pi)	10	1	1	2	5	1	20	Preserve
VMA - Urine (Probably Pi)	8	1	1	1	4	1	16	Preserve
Metanephrines - Urine (Pi)	3	1	1	2	1	1	9	Omit
Catechols - Urine (Pi)	9	1	1	2	5	1	19	Preserve
Histamine - Urine (Pi)	1	2	1	3	2	1	10	Omit
5-HIAA - Urine (Probably Pi)	8	1	1	2	5	1	18	Preserve

*See Legend at End of Table

Table 4.2-3. On-Board vs Post-Flight Tradeoff (Cont)

Measurement	Physiological Significance/ Value 1 - 10	Technical Feasibility		Safety 1 - 10	Redundancy Or Overlap (More (Less) 1 - 5	Development Lead Time 1 - 4	Rating	GE Recommendation On-Board, Preserve, Omit
		Complexity 1 - 8	Skill 1 - 6					
Urine (Cont)								
Accurate Urine Volume	10	8	6	10	5	2	41	On-Board
Creatine & Creatinine - Urine	9	3	2	5	5	2	26	Preserve
N, Ca, P, Na, K, Cl, Mg	10	1	1	2	4	1	19	Preserve
Parathyroid Hormone - Urine (Nelson Technique) (Pi) PFIIR	4	1	1	2	1	1	10	Omit
Sulfate - Urine (PFIIR)	5	3	2	5	3	2	20	Preserve
Oxalated Blood								
Hemoglobin (Cont.)	9	5	3	8	3	2	30	On-Board
Hemoglobins (OB) (Fractionation)	1	2	2	1	2	2	10	Omit
Oxalated Plasma								
Total Protein - Plasma[1]	7	3	2	5	3	2	22	Preserve
Heparinized Blood								
Capillary Blood, pO_2, pCO_2,* and pH	3	1	1	9	3	1	a	Omit
RBC Fragility (Osmotic)	1	2	1	3	1	1	9	Omit
Methemoglobin (OB)	1	2	2	1	3	1	10	Omit
Lymphocyte Karotyping (Probably Pi)	10	3	2	8	5	2	30	On-Board
WBC Mobilization (Rebuck Technique)	1	2	1	1	1	1	7	Omit
RBC Enzyme Studies (Pi)	1	1	1	3	3	1	10	Omit
Heparinized Plasma								
Immunoglobulins and Fibrinogen (OB)	4	2	2	1	2	1	12	Preserve
ACTH - Blood (Pi)	7	2	2	8	4	1	22	Preserve
17-Hydroxycorticosteroids - Blood (Pi)	2	1	1	2	1	1	8	Omit
Citrated Plasma								
Fibrinolytic Activity (PFIIR)	4	1	4	5	5	1	20	Preserve
Whole Blood with any Anticoagulant								
RBC Mass - DFP^{32} or Cr^{51}	10	5	3	8	5	3	34	On-Board
RBC Survival - DFP^{32} or Fe^{59}	10	5	3	8	5	3	34	On-Board

* See Legend at End of Table

Table 4.2-3. On-Board vs Post-Flight Tradeoff (Cont)

Measurement	Physiological Significance/ Value 1 - 10	Technical Feasibility		Safety 1 - 10	Redundancy Or Overlap (More) (Less) 1 - 5	Development Lead Time 1 - 4	Rating	GE Recommendation On-Board, Preserve, Omit
		Complexity 1 - 8	Skill 1 - 6					
Plasma with any Anticoagulant								
Protein Electrophoresis - Plasma	8	2	2	1	5	1	19	Preserve
Plasma Volume - RISA	9	5	3	8	5	3	33	On-Board
Plasma Volume On-Board (PFIIR)	9	5	3	8	5	3	33	On-Board
Plasam Volume (P&P)	Not Considered in Trade-Off Since this Measurement made on the Ground							
Whole Blood with No Anticoagulant								
Total Body Water (Breatholator or Deuterium)	7	1	1	2	2	1	14	Preserve
Blood Cell Morphology	10	4	2	8	5	2	31	On-Board
Reticulocyte Count	10	5	2	9	5	2	31	On-Board
Hematocrit	10	6	4	9	5	2	36	On-Board
Bleeding Time	8	8	6	9	4	4	39	On-Board
Clotting Time	8	6	4	9	4	4	35	On-Board
Clot Retraction*	2	3	4	8	1	2	c	Omit
Platelet Adhesiveness (PFIIR)	1	1	1	2	1	2	8	Omit
Serum								
Bilirubin - Serum[1]	8	3	2	5	4	2	25	Preserve
Bicarbonate* - Blood	6	3	1	7	4	1	b	Omit
Glucose - Blood (OB)*	6	3	2	5	4	2	22	Preserve
LDH[1] & LDH Isoenzymes (OB)	4	2	2	1	3	1	13	Preserve
SGOT[1] - Serum	6	3	2	5	4	2	22	Preserve
SGPT - Serum	6	3	2	5	4	2	22	Preserve
Prothrombin Consumption	5	3	2	8	5	2	25	Preserve
Transferins (OB)	2	1	2	7	3	1	16	Preserve
Ca & PO_4 - Serum (Probably Pi)	10	2	2	4	4	1	23	Preserve
Cholesterol - Serum (Probably Pi)	5	2	2	2	3	1	15	Preserve
BUN (Probably Pi)[1]	7	3	2	5	5	2	24	Preserve
Uric Acid - Blood (Pi)	6	2	2	5	4	1	20	Preserve
Alkaline Phosphatase - Serum[1] (Probably Pi)	6	3	2	5	4	2	22	Preserve
CPK - Serum (Pi)[1]	6	3	2	5	4	2	22	Preserve
ADH - Serum (Pi)	1	1	1	2	1	1	7	Omit
Electrolytes - Serum	10	3	2	4	4	1	24	Preserve
Complement Titration	2	1	1	5	4	1	14	Preserve
Antibody Titration	4	2	2	5	4	2	19	Preserve
Serum Free Thyroxine (T_4)	6	1	1	4	3	2	16	Preserve
TBPA (Probably Pi)	3	2	2	1	2	1	11	Omit
PBI	8	3	2	1	4	1	19	Preserve
Histamine - Blood (Pi)	1	2	1	3	2	1	10	Omit

*See Legend at End of Table

Table 4.2-3. On-Board vs Post-Flight Tradeoff (Cont)

Measurement	Physiological Significance/ Value 1 - 10	Technical Feasibility		Safety 1 - 10	Redundancy Or Overlap (More) - (Less)	Development Lead Time 1 - 4	Rating	GE Recommendation On-Board, Preserve, Omit
		Complexity 1 - 8	Skill 1 - 6					
Mineral Metabolism by Isotopic Techniques (PFIIR)	6	1	1	6	1	1	16	Preserve
Blood Lipids (PFIIR)	6	2	2	2	3	1	16	Preserve
Thyroid Bound Globulin (T_3) (Pi) (PFIIR)	3	2	2	1	2	1	10	Omit
TSH (Pi) (PFIIR)	2	1	1	2	2	1	9	Omit
Parathyroid Hormone - Serum (Radioimmune Technique) (Pi) (PFIIR)	8	1	1	2	5	1	18	Preserve
Calcitonin - Serum (Pi) (PFIIR)	7	1	1	2	3	1	15	Preserve
Insulin Assay (Pi) (PFIIR)	3	1	1	2	2	1	10	Omit
Glucagon Assay (Pi) (PFIIR)	3	1	1	1	2	1	9	Omit
Serotonin (5-HIAA) -Blood (Pi)	3	1	1	1	1	1	8	Omit

*LEGEND

NASA Notations as Per Letter, 21 November 1967, S. Vinograd to R.W. Lawton

OB = On-Board

Pi = Post-Flight on In-Flight Samples

P&P = Pre- and Post-Flight

PFIIR = Provide for Installation if Required

\+ = On-Board Urinalysis - Combistix (Ames) or equivalent for glucose, protein, pH and acetone.

* = Problems with measurement

(a) See discussion on pO_2, pCO_2, and pH in Section 4.2.2.1.4.

(b) See discussion on bicarbonate in Section 4.2.2.1.4.

(c) See discussion on clot retraction in Section 4.2.2.1.4.

[1]These measurements will be performed on-board with a post-flight back-up.

4.2.2.1 Rationales for On-Board vs Post-Flight Trade-Off

For each on-board, post-flight and omit decision, a rationale is given, as well as a suggested measurement frequency. In addition, selected measurements were chosen to be performed on-board, as a test of methods and equipment, with a post-flight backup to assure data of research quality.

4.2.2.1.1 On-Board with Post-Flight Back-up

After the on-board vs post-flight trade-off was completed, two of the three groups into which the measurements fell (on-board and preserve for post-flight analysis) were further examined. Certain wet chemical measurements were selected for performance on-board, with a post-flight back-up. These are shown in Table 4.2-4. The reason for their choice is quite simple: the methods for these tests are developed to the point where the major limiting factors for their on-board use center on the development of a flight qualified spectrophotometer/densitometer and ancillary expedables, such as volumetric capillary pipettes and cuvettes designed for use in weightlessness. The lead time required through flight qualification of the hardware is less than two years. Furthermore, these assays, when performed on-board subserve the following functions:

a. Form a screening test for health and safety purposes (quasi-real-time data is obtained);

b. Test flight hardware to be used on longer missions

c. Test flight methods applicable to additional (other) assays.

Although the measurements shown are performed using simplified techniques, none at the present time has the requisite combination of sensitivity, precision and accuracy mandatory for research quality data. Dr. Samuel Natelson, Mechael Reese Hospital, Chicago, has developed a method using paper tapes (see Paragraph 4.2.1 for description) impregnated with appropriate reagents. Three tests are now available (blood glucose, urea and total protein) but the present accuracies and precisions of $\pm$ 10 percent must each be brought to $\pm$ 5 percent or better to qualify as the method of measurement for IMBLMS. Assuming that continued development is supported, some tape methods can be used on-board in the 1971 time period.

Table 4.2.4. On-Board Tests With Post-Flight Backup

MEASUREMENT	FLUID	QUANTITY (ML/TEST)	WAVELENGTH (Mμ)
Glucose	Serum	0.010	340
Alk. Phos.	Serum	0.025	415
SGOT	Serum	0.050	340
Bilirubin (Total)	Serum	0.050	560 + 600
CPK	Serum	0.05	340
BUN	Serum	0.05	515
LDH	Serum	0.05	340
Protein (Total)	Plasma	0.05	550

Smith, Kline Instrument Company, a division of Smith, Kline and French Laboratories has developed the Eskalab* Clinical Chemistry System which is largely based on research performed by Calbiochem. This "system" (see Paragraph 4.2.1 for description) offers some methods (glucose, alkaline phosphatase, SGOT, SGPT, total bilirubin, CPK, and LDH) of interest. Double blind studies on a few of these tests have been run in several hospital laboratories in the Philadelphia area, but no measures of accuracy and precision have yet been assigned to each method. Modifications of cuvettes and reagent packaging will be required for flight use. CPK, LDH, SGOT and Glucose assays can be performed with enzymes that are dependent on NAD as the coenzyme. For these and other measurements using NAD-dependent enzymes such as SCPT, glucose-6-phosphate dehydrogenase, pyruvate and lactate, only one wave-length, 340 $m\mu$, is needed for photometric determinations. If on-board wet chemistries were to be confined to this limited group of measurements, instrument development would be greatly simplified; however, the versatility that a spectrophotometer or a group of interference filters offer would be lost.

Dade Reagents, Inc. and Harleco, both subsidiaries of the American Hospital Supply Corporation have methods similar to those of SKI, which can be adapted for use in weightlessness. Table 4.2-4 then, represents a list of measurements, which are feasible to do on-board, if development can be funded.

The post-flight backup for each of these measurements is strongly recommended because, even with extensive ground testing, the hypothesis that the methods can be used during flight must be tested in orbit. Thus, a preserved sample is essential if each experiment is to be supported by adequate data of good quality. Conversely, should preserved samples be lost or damaged, the in-flight measurements at least furnish some information on the blood chemistry of the crew.

Each of the measurements recommended for on-board performance, with a post-flight backup, is treated separately below, with a rationale for its inclusion in this category.

Measurement	Recommendation	Frequency
Alkaline Phosphatase - Serum	On-Board with Preserved Post-Flight Back-up	Once a Week

JUSTIFICATION - RATIONALE

Serum alkaline phosphatase levels are indirect measures of liver, kidney and parathyroid function. It is also altered by metasfatic lesions of bone. Post-flight analysis of preserved serum samples should be performed as a check on the in-flight assays which can be viewed as part of the health and safety screening procedure.

Measurement	Recommendation	Frequency
BUN	On-Board with Preserved Sample for Post-Flight Back-up	Once a Week

JUSTICICATION - RATIONALE

BUN is a useful measure of renal function which is altered by kidney disease, excessive protein breakdown and dehydration. The last two conditions may be encountered in space flight in view of the loss of water and changes in lean body mass which was evident in some Gemini astronauts. Chemical procedures for measuring BUN are lengthy and difficult, and involve the use of some toxic chamicals. However, both paper tape and enzymatic methods, adaptable to use on-board a spacecraft, are available. The in-flight measurement is part of the health and safety monitoring with the post-flight assay insuring that high quality data for research purposes is obtained.

Measurement	Recommendation	Frequency
Bilirubin - Serum	On-Board with Preserved Sample for back-up	Once a Week

JUSTIFICATION - RATIONALE

Serum bilirubin level is a sensitive indicator of biliary obstruction as well as hepatic function in general. It is also changes in anemias, including that due to decreased erythrocyte format formation, and cardiac failure. Because of the change observed in red cell mass on Gemini flights, it is a significant parameter for study. Conventional techniques are difficult, for the most part, and some reagents employed in routine analysis are toxic. However, a simplified technique is available which could be used on-board, with a post-flight analysis on a preserved sample as a back-up, see Paragraph 4.2.1.

Measurement	Recommendation	Frequency
CPK - Serum	On-Board with Preserved Sample for Back-up	Once a Week

JUSTIFICATION - RATIONALE

The level of serum creatine phosphokinase is altered in certain disease states such as myocardial infarctions, myocarditis, muscular dystrophy, cerebrovascular disease and hypothyroidism. These conditions are not likely to occur in healthy male adults. But CPK is also changed by muscle trauma and severe exercise. Differences between changes in ground-based controls and astronauts in space flight may well yield insight into the metabolism and energy expenditure required for space missions. It is recommended that samples be taken for this purpose. Older procedures for analysis are complicated and difficult, but a newer method can be used and tested on-board. Since the little available literature that exists suggests that preservation does not alter values significantly, post-flight measurements should also be made upon preserved samples.

Measurement	Recommendation	Frequency
Glucose - Blood	On-Board with Preserved Post-Flight Back-up	Once a Week

JUSTIFICATION - RATIONALE

Normal blood glucose levels (in fasting subject) are necessary for the health and adequate functioning in astronauts. Testing glucose levels would permit insight into the effect of space flight on carbohydrate metabolism, liver and pancreas function. Levels are not likely to alter drastically in the healthy male adult, but since procedures for measuring glucose which can be modified for on-board use are available, this measurement can be performed on-board. As a check on the in-flight analyses, preserved samples can be assayed post-flight.

Measurement	Recommendation	Frequency
LDH	On-Board	Once a Week
LDH Isoenzymes	Preserve	Once a Week

JUSTIFICATION - RATIONALE

On the ground, marked changes in LDH (lactic dehydrogenase) concentration and in the isoenzyme electrophoretic pattern only occur in certain severe disease states which do not occue in healthy, adult males, e.g. myocarial or pulmonary infarcation, acute hepatitis, muscular dystrophy, certain anemias and leukemias, etc. The technique for analysis of LDH isoenzymes is difficult and time consuming. Although some change in pattern and concentration may occur under the conditions of space flight, none deleterious to health and safety are expected. This measurement on isoenzymes should be performed post-flight on in-flight samples with an LDH assay performed on-board (with post-flight back-up) as a part of the in-flight screening.

Measurement	Recommendation	Frequency
SGOT - Serum	On-Board with Preserved Sample for Back-up	Once a Week

JUSTIFICATION - RATIONALE

This enzyme (serum glutamic oxaloacetic transaminase) is highly useful in diagnosing disease states of the heart (myocardial infarct), liver (obstructive jaundice, hepatitis, cirrhosis, infectious mononucleosis and neoplasm), muscle and blood (leukemia or anemia). Drug toxicities of various types are also reflected in the level of SGOT. In the healthy adult man, however, the only effects which may be seen are changes due to trauma (accidental or operative). Because of its versatility as a diagnostic indicator, the measurement should be done. Procedures for on-board use can be readily adapted from techniques new available, see Section 4.2.1. Post flight analysis of preserved samples is recommended as a back-up.

Measurement	Recommendation	Frequency
Total Protein - Plasma	On-Board with Preserved Sample for Back-up	Once a Week

JUSTIFICATION - RATIONALE

Plasma protein concentration varies due to many factors such as disease, radiation and dehydration. The first factor should not be important in healthy adults unless space flight itself acts as a "disease" and alters plasma protein concentrations. Radiation and dehydration may occur during space flight and thus plasma protein concentration should be monitored. Conventional procedures for analysis do present a hazard. A newer method, although not completely proven is recommended for on-board use, see Paragraph 4.2.1, post-flight analysis of preserved samples is recommended as a back-up.

4.2.2.1.2 On-Board Measurements

Each measurement receiving a rating of 30 or better in the on-board vs post-flight trade-off (Table 4.2-3) is included in this group.

A number of measurements such as feces wet weight, hematocrit, clotting time, and miroscopic examination of urine, must be done on-board if they are to be done at all. A major limitation, however, in the on-board selection was equipment design.

In general, the equipment required to perform these measurements is not available at present in flight-qualified form. Studies by General Electric, however, reflected in Table 4.2-3 under "Development Lead Time", show the feasibility of developing such flight qualified hardware within two years or less.

A centrifuge concept for the separation of plasma or serum has been described in previous reports to NASA (Final report, NASA Contract, NASW-1562, and IMBLMS Phase B Final Report). A wasking machine concept is described in this report for collection of sweat electrolytes. Spectrophotometer design must take into account g-loads during launch. Equipment for lymphocyte karyotyping is feasible, as is an on-board radiation sensor for counting isotopes used in RBC mass and survival studies. Each of the on-board measurements is discussed below.

Measurement	Recommendation	Frequency
Accurate Feces Wet Weight	On-Board	Every Day

JUSTIFICATION - RATIONALE

This measurement is essential to fluid balance and nutrition studies. Since a mass measurement device is available, the wet weight can be done on-board more accurately than would be the case if wet weights were obtained post-flight on preserved samples.

Measurement	Recommendation	Frequency
Accurate Fluid In-take Measurement	On-Board	Every Day

JUSTIFICATION - RATIONALE

This measurement is necessary for study of fluid balance which was observed to become negative in some Gemini flights. This measurement is important to the health and safety of the astronauts. If made periodically throughout a flight, it will assist in determining the time course of development of a significantly negative or positive fluid balance.

Measurement	Recommendation	Frequency
Accurate Urine Volume Measurement	On-Board	Every Day

JUSTIFICATION - RATIONALE

This measurement is essential to fluid and electrolyte balance studies. Storage of the total voidings of all three crew members is impossible so that the measurement must be made on-board. GFE equipment has been proposed to accomplish this task.

Measurement	Recommendation	Frequency
Bleeding Time	On-Board	Once a Week

JUSTIFICATION - RATIONALE

Although not a quantitative test, bleeding time measurement may indicate changes in the clotting mechanisms of the astronauts. This can only be measured in situ and becomes more important in radiation exposure.

Measurement	Recommendation	Frequency
Blood Cell Morphology	On-Board	Every Three Days

JUSTIFICATION - RATIONALE

Blood cell morphology studies require measurements of RBC (Total), and WBC (Total) and the preparation and fixation of cell smears for differential white counts and platelet estimates in-flight. Such data is important to ascertain the health of the astronauts especially if exposed to significant amounts of radiation. For these reasons, immediate in-flight analyses would be desirable at frequent intervals.

Measurement	Recommendation	Frequency
Clotting Time	On-Board	Once a Week

JUSTIFICATION - RATIONALE

Clotting time, though only a qualitative test, does provide a measure of the functioning of the blood clotting factors in cases of exposure to radiation and would permit a gross check on the response of clotting factors to a weightless environment. It cannot be done on preserved blood and, therefore, must be measured in-flight.

Measurement	Recommendation	Frequency
Fluid Balance	On-Board	Every Day

JUSTIFICATION - RATIONALE

Proper fluid balance is essential to the health of the astronauts. Its measurement can only be performed in-flight. This measurement is redundant, however, with accurate fluid intake, feces wet weight, accurate urine volume and sweat measurement.

Measurement	Recommendation	Frequency
Hematocrit	On-Board	Once a Week

JUSTIFICATION - RATIONALE

This measurement yields essential information about the astronauts' health. It is also essential to such measurements as plasma volume and red cell mass. It cannot be determined on preserved samples of blood. For these reasons, in-flight measurement is recommended.

Measurement	Recommendation	Frequency
Hemoglobin	On-Board	Once a Week

JUSTIFICATION - RATIONALE

This measurement yields essential information about astronauts' health and is a correlate of the oxygen combining capacity of the blood. If done in-flight, this information would be immediately available. Post-flight analysis is feasible.

Measurement	Recommendation	Frequency
Lymphocyte Karyotyping	On-Board	Once a Week

JUSTIFICATION - RATIONALE

Immediate in-flight analysis is preferable; however on-board data handling would not only over-tax the computer, but would also entail a large weight penalty be addition of an optical scanner and a photo enlargement-development capability. The latter imposes a toxicity hazard of unknown magnitude. Therefore, the on-board procedure results in a photograph and a slide, both of which can be examined post-flight for the actual analysis which produces data.

Viable, mitotically competent lymphocytes can only be preserved by controlled freezing (1° C/minute) to -30°C in protective adjuvants and storage at -70°C or below. Preservation equipment is complex, heavy, and uses large amounts of power. The preservation technique is not used routinely anywhere, is still in the developmental stage and is employed only by a few research laboratories.

On-board cultivation of lymphocytes and preparation of cell smears is recommended even though they entail lengthy and complex procedures. This measurement is recommended for inclusion because of its significance as a biological radiation dosimeter and because weightlessness alone or in combination with other factors may cause chromosomal aberrations and anomalies.

Three options do exist as growth items:

a. direct transmission of microscope fields by TV with all data reduction on the ground.

b. on-board enlargement of pictures of microscope fields with TV transmission of the pictures to ground for analysis.

c. on-board enlargement of pictures of microscopic fields, cutting of pictures, reconstruction of chromosomes, optical scanning and first stage data reduction on-board.

Measurement	Recommendation	Frequency
Plasma Volume	On-Board	Once a Week

JUSTIFICATION - RATIONALE

Plasma volume was one of the parameters which was observed to change significantly as a result of space flight during some of the Gemini missions. For this reason, every effort should be made to measure plasma volume routinely on all IMBLMS flights. The method of choice seems to be labeling of serum with radio-iodinated serum albumin (I^{125}). Measurement is not difficult or time consuming and could be readily performed by the astronauts during the course of flights. It would yield information concerning the astronauts' health and permit ground control to recommend corrective action by the astronauts such as ingestion of greater amounts of liquid. Injection of the isotope, which has a half-life of 56-days should be done prior to launch.

Measurement	Recommendation	Frequency
RBC Mass - DFP^{32} or Cr^{51}		

JUSTIFICATION - RATIONALE

RBC Mass was one of the measurements which was observed to vary drastically post-flight on the Gemini missions. Whether this was due to the enriched oxygen tension of the spacecraft or to space flight itself, is still unresolved.

It is also of great importance to the health of the astronauts. The technique of measurement is not difficult nor is it hazardous or time consuming. For these reasons, on-board measurement is recommended.

Measurement	Recommendation	Frequency
RBC Survival - DFP^{32} or Fe^{59}	On-Board	Once a Week

JUSTIFICATION - RATIONALE

Measurement of RBC survival may yield information as to the mechanism of loss of RBC mass found in some Gemini astronauts. The technique is relatively easy, takes little time and is important to ascertaining the health of the astronauts especially if exposed to radiation. For these reasons, on-board analysis is recommended.

Measurement	Recommendation	Frequency
Reticulocyte Count	On-Board	Once a Week

JUSTIFICATION - RATIONALE

The fraction of reticulocytes occurring in peripheral blood is a measure of hemopoetic activity of the reticulo-endothelial system. Because of the evidence of loss of red cell mass on Gemini flights, and because of concern about the effects of weightlessness and space radiation on the production of erythrocytes, this measurement is of importance to the understanding of the effect of space flight upon man. Some of the procedures for producing the necessary microscope slides (i.e., the actual smearing of blood cells and fixing of the smear) must be performed immediately upon withdrawal of the sample. Therefore, on-board preparation and possible analysis of samples is recommended.

Measurement	Recommendation	Frequency
Routine Urinalysis	On-Board	Once a Week

JUSTIFICATION - RATIONALE

This group of measurements can serve as a useful indicator of space flight changes in fluid balance and renal function as well as an indirect measure of other conditions. Certain of the measurements involved such as microscopic examination, color and specific gravity must be done shortly after urine collection if at all. They cannot be meaningfully performed on preserved urine. Glucose, protein, pH and acetone bodies can be determined for health and safety purposes by bibulous paper strips impregnated with reagents, such as Combistix (Ames).

4.2.2.1.3 Post-Flight Measurements on Preserved Samples

Two techniques, suggested by NASA, for on-board use have been excluded as safety hazards; they are thin layer chromatography (TLC) and alectrophoresis. TLC is suggested as a method only for serum free thyroxine (T_4). Serum thyroxine level is not critical information. Since this measurement is the only real need for TLC and because many solvents used in TLC are volatile, both the measurement and TLC were d ropped from consideration. Like TLC, electrophoresis is routinely used in ground-based laboratories. We find no real need for the proposed electrophoretic data during flight, and volatile solvents, shock hazard and heat dissipation characterize this technique.

By and large, those measurements which have considerable but not immediate physiological interest, and/or for reasons of procedural complexity or safety should not be performed on-board (see Table 4.2-3) are included in the "Preserve" category. As appropriate methods are developed, a number of these may be promoted to the on-board group.

A rationale for inclusion of each of the measurements in the Preserved Sample group follows.

Measurement	Recommendation	Frequency
ACTH - Blood	Preserve	Once a Week

JUSTIFICATION - RATIONALE

This measurement would give us a direct measure of the functional integrity of the pituitary. No information at present exists on the effect of space flight on this gland. For thie reason and because of its importance to the functioning of other endocrines, an effort should be made to collect samples for this measurement. Procedures for analysis are difficult and time consuming, and the general health of the astronauts can be monitored by simpler means. For these reasons, post-flight analysis of in-flight samples is recommended.

Measurement	Recommendations	Frequency
ADH - Urine	Preserve	Once a Week

JUSTIFICATION - RATIONALE

In view of the dehydration which was observed to occur in some Gemini astronauts, ADH levels in the body may be significantly altered by space flight. Excretory levels of ADH should be indicative of any changes which do occur. Current techniques for measuring ADH employ a bioassay method involving the use of several hydrated rats for each measurement. Provision has not been made, however, for the maintenance of on-board animal laboratory colonies, and therefore, ADH measurements should be made on preserved urine post-flight.

Measurement	Recommendation	Frequency
Blood Lipids	Preserve	Once a Week

JUSTIFICATION - RATIONALE

Space flight may have an effect on lipid mobilization and metabolism. There are no other direct measures of this function on the NASA measurements list except for blood cholesterol. In-flight procedures for analysis would be difficult and hazardous, however, so post-flight analysis of preserved samples is the choice.

Measurement	Recommendation	Frequency
Aldosterone - Urine	Preserve	Once a Week

JUSTIFICATION - RATIONALE

Little is known about the effect of space flight on electrolyte balance. In view of the changes in fluid balance observed on some Gemini flights, and anticipated as the result of bed rest studies, electrolyte balance may also be affected including renal tubular reabsorption of solium. While blood and urine sodium and potassium levels may reflect such changes, measurement of urinary aldosterone will be a direct indication of whether the change is horomal. Adosterone measurement involves extremely complex, difficult and time consuming techniques and should be measured post-flight on preserved samples.

Measurement	Recommendation	Frequency
Antibody Titration	Preserve	Once a Week

JUSTIFICATION - RATIONALE

Techniques for antibody titration require great skill even under one-g conditions. For on-board analysis, the technique entails carrying a number of reagents dependent on the number of antigens tested. On-board results would not dictate any immediate prophylectic measures and, because antibodies can be successfully preserved with little or no change in titers over long periods of time, titrations should be performed post-flight on preserved samples.

Measurement	Recommendation	Frequency
Body Microflora	Preserve (Cultures)	Once a Week

JUSTIFICATION - RATIONALE

For the conduct of microbiology experiments, sampling and culturing must be done on-board. Other procedures can well be left to the post-flight period including subculturing and identification. Changes in the microecology of each astronaut may occur as the result of their isolation during space flight. Whether these changes will parallel those observed in ground-based chamber studies and jeopardize the astronauts' health, are legitimate research questions. In order to interpret such findings in astronauts, a history of their micro-ecologies by body and environmental sampling is essential.

Measurement	Recommendation	Frequency
Ca and PO_4 - Serum	Preserve	Once a Week

JUSTIFICATION - RATIONALE

There is concern among many physiologists that prolong space flight may produce the kind of dense bone changes encountered among patients immobilized in bed rest. These two measurements relate to increased blood levels and supplment Ca and PO_4 balance studies. Some evidence exists in the form of quantitative pre- and post-flight bone radiography of the Gemini astranuts which suggest that demineralization does indeed occur and every effort should be made to confirm this hypothesis using wet chemistry techniques on prolonged flights. Techniques are difficult, lengthy and hazardous but since no immediate threat to astronauts' health is involved, these measurements should be performed post-flight on preserved samples.

Measurement	Recommendation	Frequency
Calcitonin - Serum	Preserve	Once a Week

JUSTIFICATION - RATIONALE

Thyrocalcitonin is believed to act as a regulatory agent upon calcium levels in the blood and varies directly with the blood calcium level. The measurement is related to disuse changes in bone during weightlessness. It requires, however, bioassay techniques which cannot be performed on-board currently planned IMBLMS flights. For these reasons, it is re commended that calcitonin be measured post-flight on preserved samples.

Measurement	Recommendation	Frequency
Catechols - Urine	Preserve	Once a Week

JUSTIFICATION - RATIONALE

This measurement is related to the general level of space flight stress. Since blood levels represent generally transitory phenomena, the level in pooled urine (24 hours) provides a better measure of the general stress level for the period. The technique involved is extremely complex, difficult and lengthly. The measure is not necessary to determine the operational health of the astronaut, and therefore post-flight measurement of preserved in-flight samples is recommended.

Measurement	Recommendation	Frequency
Cholesterol - Serum	Preserve	Once a Week

JUSTIFICATION - RATIONALE

Measurement of serum cholesterol on in-flight samples and comparison to pre- and post-flight values may yield information on the effect of space flight on lipid metabolism and the complex interrelations of fat mobilization and utilization in exercise and stress. Techniques, however, are difficult and involve the use of toxic and hazardous reagents.

Measurement	Recommendation	Frequency
Complement Titration	Preserve	Once a Week

JUSTIFICATION - RATIONALE

This measurement is difficult to do in absence of gravity because of liquid handling problems. This test is of lesser significance in healthy adults, but preserved samples for post-flight analysis may aid in understanding microfloral changes.

Measurement	Recommendation	Frequency
Creatine and Creatinine - Urine	Preserve	Once a Week

JUSTIFICATION - RATIONALE

The creatinine and creatine contents of the urine are remarkably constant from day to day in healthy adults. Changes in levels usually occur only in some disease states. Both compounds, however, are believed to originate in large part from muscle. Phosphocreatine is regarded as the chief chemical warehouse for energy-rich phosphate bonds used in the energy metabolism of muscle contraction. Changes in excretory levels also occur in cases of increased muscular activity or muscular atrophy. Thus, these measurements should have priority for performance. Because of the difficulty of conventional measurement techniques and the hazards involved, post-flight analysis of preserved samples is recommended. Research now in progress may result in a technique adaptable for on-board use.

Measurement	Recommendation	Frequency
Electrolytes - Serum	Preserve	Once a Week

JUSTIFICATION - RATIONALE

Procedures for measurement of electrolytes are lengthy, difficult and hazardous to do in-flight. They are, however, essential to an understanding of mineral and electrolyte balance. Since they are preservable without loss, post-flight analysis of preserved samples is recommended.

Measurement	Recommendation	Frequency
Environmental Culturing	Preserve (Cultures)	Once a Week

JUSTIFICATION - RATIONALE

See "Body Microflora".

Measurement	Recommendation	Frequency
Fibrinolytic Activity	Preserve	Once a Week

JUSTIFICATION - RATIONALE

If space flight has an effect on clotting factors, it may also affect the amount of fibrinolysin in the blood. Fibrinolysin does not normally vary significantly in the healthy adult, however. Post-flight analysis of preserved samples is recommended because procedures are difficult to perform in the absence of gravity.

Measurement	Recommendation	Frequency
5-HIAA-Urine	Preserve	Once a Week

JUSTIFICATION - RATIONALE

5-hydroxyindoleacetic acid is the principle degradation product of serotonin (5-hydroxytryptamine) which exerts important effects in the cascular system and in CNS activity. It may also have effects on mood; excesses are believed to cause hyper-excitability and hyperactivity while reduced levels in the brain are believed to be associated with depression. Because of its importance to hemeostasis and astronaut mood and performance, it is recommended that 24-hour pooled urine samples be analyzed for this constituent. The technique for analysis, however, is complex; it also requires some reagents which are toxic. Samples, therefore, should be preserved for post-flight analysis.

Measurement	Recommendation	Frequency
Hydroxyprolines - Urine	Preserve	Once a Week

JUSTIFICATION - RATIONALE

Increased urinary excretion of hydroxyprolines reflects alterations in the organic matrix of bone. In view of the concern that space flight may produce such changes, this measurement will help test this hypothesis. Analysis is difficult, and since immediate answers are not necessary, preservation for post-flight measurement is recommended.

Measurement	Recommendation	Frequency
Immunoglobulins and Fibrinogen	Preserve	Once a Week

JUSTIFICATION RATIONALE

Electrophoresis for fibrinogen and immunoelectrophoresis for immunoglobulins are difficult and lengthy procedures. In addition, if paper or cellulose acetate is used, a flammability hazard would exist. The levels may be affected by space flight especially if appreciable radiation is encountered. Both measurements should not, however, be so changed as to affect the astronauts' health and safety. For this reason, post-flight analysis of in-flight samples would seem to be the best alternative.

Measurement	Recommendation	Frequency
Mineral Metabolism by Isotopic Techniques	Preserve	See urine and feces N, Ca, P, Na, K, Cl and Mg

JUSTIFICATION - RATIONALE

This measurement should be done post-flight on preserved samples. Input-output studies of minerals can be accomplished without resorting to isotopes, and they are provided for by other measurements. Isotopic methods would permit analysis of turn-over rates in the body's mineral pools. Turn-over rates and mechanisms may well change in response to space flight, but such studies are of secondary priority. Such measurements could be the topic of a special study. Since samples for assays of minerals are being taken as a matter of course, counts can be made on those samples. If more than one radioisotope is used, the difference in energy levels of the emissions of the commonly-used isotopes is sufficient to permit counts of each to be made. Stable isotopes would require assay by mass spectrometry.

Measurement	Recommendation	Frequency
Mucoproteins - Urine	Preserve	Once a Week

JUSTIFICATION - RATIONALE

The mucoproteins (and related biocolloids) are of particular interest in assessment of bone changes. Because of the presemptive evidence that weightlessness can affect the integrity of the bone matrix, a measurement of mucoprotein excretion complements assays of Ca, PO_4, hydroxyprolines and circulating parathyroid hormone and permits a more intelligent interpretation of the data.

Measurement	Recommendation	Frequency
N, Ca, P, Na, K, Cl & Mg - Urine and Feces	Preserve	Once a Week

JUSTIFICATION - RATIONALE

This measurement is essential to mineral balance studies. Procedures for analysis are lengthy, difficult and hazardous to do in-flight, however. In addition, preservation does not alter values. Post-flight analysis of preserved samples is therefore recommended.

Measurement	Recommendation	Frequency
Parathyroid Hormone - Serum (Radioimmune Technique)	Preserve	Once a Week

JUSTIFICATION - RATIONALE

An analysis of the serum levels of parathyroid hormone may held throw light upon the mechanism of bone changes during space flight. Parathyroid levels are believed to vary inversely with blood calcium levels and directly with blood phosphates. Techniques are, however, complicated and difficult. For these reasons, post-flight analysis of preserved samples is recommended.

Measurement	Recommendation	Frequency
PBI	Preserve	Once a Week

JUSTIFICATION - RATIONALE

This measurement is still believed by many clinicians, physicians and scientists who specialize in clinical chemistry to be the best all-round test of thyroid function available. Study of thyroid activity may be helpful in understanding how space-flight affects energy metabolism and endocrine function. Procedures are, however, complicated, difficult, time consuming and hazardous. Therefore, it is recommended that measurements be made post-flight upon preserved samples.

Measurement	Recommendation	Frequency
Protein Electrophoresis-Plasma	Preserve	Once a Week

JUSTIFICATION - RATIONALE

Procedures for electrophoresis are difficult, lengthy and extremely hazardous (material used is usually paper or cellulose acetate, both of which are flammable). On the other hand, knowledge of the effect of space flight on plasma proteins could be gained by regular analysis of electrophoretic patterns if astronauts are exposed to significant amounts of ionizing radiation. Post-flight analysis of preserved samples is recommended.

Measurement	Recommendation	Frequency
Prothrombin Consumption	Preserve	Once a Week

JUSTIFICATION - RATIONALE

This measurement is the only specific and quantitative test for clotting factors which NASA has retained on its list of measurements. Although rarely of significance in the healthy adult, it requires only a small serum sample. To do this test, however, many specifically preserved biological reagents are necessary. It is also difficult and time consuming. For these reasons, post-flight analysis of preserved samples is recommended.

Measurement	Recommendation	Frequency
Pyrophosphates - Urine	Preserve	Once a Week

JUSTIFICATION - RATIONALE

Because the energy metabolism of spacecraft crews is of importance, the excretion of pyrophosphates should be monitored. Although of little interest in normal clinical situations, this measurement will aid in defining the conditions under which healthy adult males spill pyrophosphate.

Measurement	Recommendation	Frequency
Return of Total Dry Stool	Preserve	Every Day

JUSTIFICATION - RATIONALE

The return of fecal samples is very important to all nutritional and electrolyte balance studies. Lyophilization for preservation is recommended even though it entails weight and volume penalties. Alternatives are chemical preservation, or freezing of the wet stool. Penalties might be less severe using either of these methods. (Total return may not be necessary. A 15-20 gram sample of each defecation would suffice for analyses desired if thorough maxing is achieved.)

Measurement	Recommendation	Frequency
Serum Free Thyroxine (T_4)	Preserve	Once a Week

JUSTIFICATION - RATIONALE

This test is a direct measure of tetraiodothyronine (thyroxine) activity in the blood. It reflects thyroid function since thyroxine is one of the main hormones produced by the gland. One measure of thyroid competence is the PBI test and this can be considered a back-up measurement. Procedures for measuring thyroxine in the serum are difficult, lengthy and potentially hazardous. For these reasons, this measurement should be performed post-flight on preserved samples.

Measurement	Recommendation	Frequency
17-Hydroxycorticosteroids - Urine	Preserve	Once a Week

JUSTIFICATION - RATIONALE

This test is necessary to measures of metabolic activity, adrenal cortical function and reactions to stress. Changes in any or all of these areas may occur during space flight. Because the measurement is difficult, time consuming and involves the use of very toxic reagents, post-flight analysis of preserved samples is recommended.

Measurement	Recommendation	Frequency
17-Ketosteroids	Preserve	Once a Week

JUSTIFICATION - RATIONALE

This measurement is an indicator of adrenal and testicular androgenic activity in the healthy adult male. Little is currently known about the effect of space flight on androgenic activity, and this is a candidate for inclusion in any measurement list. Because the health of the astronauts is not likely to be involved and because measurement techniques are difficult, time consuming and involve the use of toxic and hazardous reagents, analysis of preserved samples is recommended.

Measurement	Recommendation	Frequency
SGPT	Preserve	Once a Week

JUSTIFICATION - RATIONALE

SGPT (serum glutomic pyruvate transaminase) changes are thought to be due to changes in liver function. In combination with SGPT levels, many differential diagnoses are possible. Its value in the healthy male adult may not change but space flight may have some specific effect on liver function. For this reason, the measurement should be included. Post-flight analysis of preserved samples is recommended. Current laboratory developments may permit addition of this measurement to the on-board group at a later date.

Measurement	Recommendation	Frequency
Sulfate - Urine	Preserve	Once a Week

JUSTIFICATION - RATIONALE

This measurement dealing with sulfur metabolism, complements that obtained from animo acid analysis. In-flight analysis need not be performed. However, post-flight analysis of preserved samples is recommended.

Measurement	Recommendation	Frequency
Sweat Measurement and Sample Return	Preserve	Once a Week

JUSTIFICATION - RATIONALE

Measurement of sweat and its constituent electrolytes is necessary for fluid and mineral balance studies. Volume output could not be measured in-flight. The electrolytes from sweat tests and/or clothes and body rinses have to be returned for ground analysis because te chniques are lengthy, difficult and, or hazardous. Rather than save all clothing discarded in flight, if a washing machine, whose design has been considered were onboard, it could elute electrolytes with distilled water (which would be passed through ion exchange resins or lyophilized) and wash the clothing which then could be returned to service.

Measurement	Recommendation	Frequency
Total Amino Acids - Urine	Preserve	Once a Week

JUSTIFICATION - RATIONALE

Abnormal metabolism of proteins as well as certain pathological conditions are reflected in the levels of amino acids excreted in the urine. Since metabolism and nutrition is an area of importance in the study of the effects of space flight upon healthy adult males, an effort should be made to make this measurement. The technique involves difficult and possibly hazardous methods and reagents. For these reasons, preservation of in-flight samples for post-flight analysis is recommended.

Measurement	Recommendation	Frequency
Total Body Water (Breatholator or Deuterium)	Preserve	Once a Week

JUSTIFICATION - RATIONALE

In view of the dehydration which occuredon the Gemini missions, it is important to examine the Apollo astronauts for changes in this parameter. Health and safety are probably not factors here, however. On-board fluid balance studies (input-output) will tell ground control whether the men should be drinking more water or not. Measurement of total body water will help to verify in a precise and accurate way the results of the fluid balance measurements. Since the procedure is difficult to do in the absence of gravity, preservation of samples for post-flight analysis is recommended.

Measurement	Recommendation	Frequency
Transferins	Preserve	Once a Week

JUSTIFICATION - RATIONALE

Electrophoretic techniques for quantitation of serum transferins levels are complicated, time consuming and hazardous (flammable materials such as paper). Changes of physiological rather than clinical interest which could occur as a result of weightlessness and/or radiation should be noted on preserved samples.

Measurement	Recommendation	Frequency
Uric Acid - Blood	Preserve	Once a Week

JUSTIFICATION - RATIONALE

Uric acid is the principal end product of purine catabolism. Its serum level is sometimes increased by high purine diet, gout, kidney disease and leukemia. It may be of research interest to examine serum levels in samples obtained during space flight since the results will have some bearing on the metabolism and nutrition experiments. Since in-flight determination would be difficult and possibly hazardous, measurements should be made post-flight on in-flight samples.

Measurement	Recommendation	Frequency
VMA - Urine	Preserve	Once a Week

JUSTIFICATION - RATIONALE

Vanilmandelic acid is the principal end-product of the metabolism of the pressor amines, epinephrine and norepinephrine. Since the stress of space flight is little understood in terms of physiological changes, sampline for this compound, as well as the catecholamines, should be undertaken. Since such analysis is not necessary to assure the health of the astronauts and since it is difficult and time consuming, post-flight analysis of preserved amples is recommended.

4.2.2.1.4 Measurements Omitted

Some twenty-odd measurements are recommended for exclusion from IMBLMS. Measurements reluctantly consigned to this group are blood pH, bicarbonate, pO_2 and pCO_2. The likelihood of promoting them to on-board status (these measurements cannot be made on preserved samples) is dependent upon how much R&D will be supported in the area of micro, multipurpose electrodes concurrent with studies on correlation factors among assays made on capillary, venous and arterial blood.

The other measurements, listed below not only ranked low in several tradeoff categories, but also lacked the criteria of relatively high physiological significance.

Measurement	Recommendation	Frequency
ADH - Serum	Omit	---

JUSTIFICATION - RATIONALE

It is not necessary to measure serum ADH levels in addition to excretory levels in urine, since serum levels usually reflect transitory phenomena. If the kidney does not respond normally to ADH in space flight, fluid balance plus excretory levels of ADH will indicate this. In addition, should abnormalities be observed in these parameters, provision can be made for measuring blood levels of ADH in protocols for later flights.

Measurement	Recommendation	Frequency
Bicarbonate - Blood	Omit	---

JUSTIFICATION - RATIONALE

Bicarbonate levels are difficult to perform even in a well equipped laboratory. Considerable skill and finesse are required because the sample must be taken and handled anaerobically. Furthermore, the accuracy obtained is dependent upon whether or not back titration is carried to the specific pH of the fresh sample. (See discussion under pH)

Measurement	Recommendation	Frequency
Capillary Blood 0_2, $C0_2$ and pH	Omit	---

JUSTIFICATION - RATIONALE

These measurements must be done on-board immediately after sampling. Accurate and precise results are difficult to obtain on the ground. Problem areas for venous or arterial blood are withdrawal and handling of the blood, temperature control in all three determinations and electrode-sample junction potentials in pH determinations. The relationships between measurements on capillary blood and those of arterial and/or venous blood remain to be systematically established.

Measurement	Recommendation	Frequency
Clot Retraction	Omit	---

JUSTIFICATION - RATIONALE

Clot retraction observation must be made on fresh blood. Usually,unstoppered tubes, partially filled with whole blood are allowed to stand in a water bath at 37°C. Periodic inspections are made and the times that retraction begins and ends are noted, as well as the quality of the clot and amount of serum extruded. The problems inherent in dealing with liquids under weightlessness would make considerable modification of the method necessary. Although development of flight-qualified methodology and hardware could be accomplished in less than two years, the information obtained from this measurement on healthy adult males is probably not worth the cost.

Measurement	Recommendation	Frequency
Insulin Assay	Omit	---

JUSTIFICATION - RATIONALE

See "Glucagon Assay"

Measurement	Recommendation	Frequency
Glucagon Assay	Omit	---

JUSTIFICATION - RATIONALE

The physiological significance of glucagon is not yet fully understood. In addition, there is no standard accepted technique for its measurement, and large blood samples are required. It is believed to be an insulin antagonist. The levels of blood glucose should give us sufficient information concerning carbohydrate metabolism on early flights. If anomalous results are obtained, provision can be made on later flights to sample for both insulin and glucagon. For the present IMBLMS mission, however, both measurements should be omitted.

Measurement	Recommendation	Frequency
Growth Hormone	Omit	---

JUSTIFICATION - RATIONALE

Growth hormone is not secreted in detectable amounts in the healthy male adult. Should other measurements imply the existence increased or decreased secretory activity in the astronauts as a consequence of space flight, later missions might include sampling for this parameter as a special study. For the time being, however, it should be omitted.

Measurement	Recommendation	Frequency
Hemoglobin (electrophoresis)	Omit	---

JUSTIFICATION - RATIONALE

Electrophoretic analysis of blood hemoglobins does not seem warranted since unusual hemoglobins are genetically determined. Thus, patterns should not vary appreciatively from those obtained pre-flight.

Measurement	Recommendation	Frequency
Histamine - Blood	Omit	---

JUSTIFICATION - RATIONALE

This test is probably of little significance in healthy, adult males. Neither a poll of medical school faculty members, nor a literature survey have resulted in a logical basis for performance of this test.

Measurement	Recommendation	Frequency
Histamine - Urine	Omit	---

JUSTIFICATION - RATIONALE

Test of limited significance. (See Histamine - Blood)

Measurement	Recommendation	Frequency
RBC Enzyme Studies	Omit	---

JUSTIFICATION - RATIONALE

There is some concern among physiologists that increased oxygen tension may later the enzyme systems of erythrocytes. Such an interest could be better served by hypobaric, increased O_2 tension chamber studies especially since measurement in-flight, or preservation of erythrocytes for post-flight analysis are extremely difficult.

Measurement	Recommendation	Frequency
RBC Fragility (Osmotic)	Omit	---

JUSTIFICATION - RATIONALE

This measurement is physiologically of second priority. It is difficult, time-consuming, requires a number of salt solutions of varying tonicity and must be done on-board. For these reasons, it should be omitted.

Measurement	Recommendation	Frequency
Metanephrines	Omit	---

JUSTIFICATION - RATIONALE

Since it is planned to measure urinary excretion of catecholamines and of 3-methoxy-4-hydroxymandelic acid (vanilmandelic acid), it is redundant to include the metanephrines in the list of measurements. VMA is the common degradation product of adrenaline, noradrenaline, metanephrine and normetanephrine. Other metabolic pathways are possible, of course, but measurement of the metanephrines would seem to be of lesser physiological significance.

Measurement	Recommendation	Frequency
Methemoglobin	Omit	---

JUSTIFICATION - RATIONALE

Methemoglobin occurs in blood only in certain cases of acute or chronic poisoning by such substances as phenylhydrazine, pyrogallol, nitrobenzene and other nitro and amide compounds. Minor degrees of methemoglobinemia may be encountered after treatment with sulfonamide drugs, nitrates, methylene blue, sulfonal, potassium chlorate, etc. Therefore, there seems to be no logical reason for including it in the IMBLMS measurement list.

Measurement	Recommendation	Frequency
Parathyroid/Hormone - Urine (Nelson Technique)	Omit	---

JUSTIFICATION - RATIONALE

It is unnecessarily redundant to measure parathyroid hormone in both serum and urine. Only small quantities are excreted and serum levels change only slowly. In addition, large quantities (50-100 ml) of urine would be required for assay. The technique itself is of the bioassay type requiring the maintenance of an animal colony. This is out of the question for currently scheduled IMBLMS flights. Power, weight and volume penalties would be prohibitive to store urine for post-flight analysis.

Measurement	Recommendation	Frequency
Platelet Adhesiveness	Omit	---

JUSTIFICATION - RATIONALE

This test is difficult to perform, requires large samples of blood, is only qualitative, and is redundant with making platelet smears. Variation is not expected to occur in healthy adults except perhaps in response to radiation exposure. While such exposure would also reduce the number of platelets, smears are to be made to count platelets routinely. The above reasons should be sufficient for omission of this measurement.

Measurement	Recommendation	Frequency
Serotonin (5-HIAA) - Blood	Omit	---

JUSTIFICATION - RATIONALE

Analysis of excreted levels of 5-hydroxyindole acetic acid should supply sufficient information. Blood levels may represent transitory phenomena and require large blood samples. Such measurements would be needlessly redundant.

Measurement	Recommendation	Frequency
17-Hydroxycorticosteroids - Blood	Omit	---

JUSTIFICATION - RATIONALE

Adrenal cortical activity can be adequately studies by measuring excretory levels of steroids in the urine. Blood levels represent transitory phenomena only; such a test would require a prohibitively large blood sample and the data obtained would be of questionable value unless the sample were taken during, or immediately after, periods of stress.

Measurement	Recommendation	Frequency
TBPA	Omit	---

JUSTIFICATION - RATIONALE

It is still the opinion of many physicians in clinical practice, physiologists and clinical chemists that the measurement of PBI gives sufficient information abour thyroid function. For this reason, it is recommended that TBPA be omitted.

Measurement	Recommendation	Frequency
Thyroid Bound Globulin (T_3)	Omit	---

JUSTIFICATION - RATIONALE

Substitute PBI. See discussions on TBPA and PBI.

Measurement	Recommendation	Frequency
TSH	Omit	---

JUSTIFICATION - RATIONALE

Thyroid stimulating hormone is, like ACTH, produced by the pituitary. Measurement of PBI and thyroxine levels in the serum should yield sufficient information concerning thyroid function. If significant decreases are observed in these latter measurements, and thyroid malfunction is suspected, provision can be made on later IMBLMS missions for sampling blood for TSH assay. On initial flights, such assays appear unnecessary.

Measurement	Recommendation	Frequency
WBC Mobilization (Rebuck Technique)	Omit	---

JUSTIFICATION - RATIONALE

The major justification for studies of WBC Mobilization relates to alterations in the micro-ecology and the potential for infection. The technique itself is traumatic. The skin is irritated chemically until it exudes fluid and leukocytes which are sampled. The open wound produced by these chemical means may take several days to heal with the possibility of infection.

The requirement for a test of this type has not been firmly established by microbiological studies of the ecology and, therefore, should be omitted.

4.2.3 IMPLICATIONS OF MEASUREMENT FREQUENCY

Ideally, for each crew member, blood, urine, and sweat samples would be taken several times each day and a stool sample at each defecation regardless of which analyses are performed on-board and which post-flight. Because of mission constraints, the question arises as to what constitutes a minimum acceptable number of samples and on what daily schedule these samples should be taken.

Regardless of the number of samples taken, each sample should be obtained at the same time of each 24-hour period.

Blood Chemistry values are highly variable with the time of day; lowest values, often in a range, heretofore considered pathologic, usually occur in the evening, although blood creatinines have been found to be highest in the early morning hours. For example, phosphate averages of 5-6 mg percent at 8:00 A.M. and 3 mg at 11:00 A.M. have been reported.

Since each astronaut will serve as his own control, and the control values will be determined during pre-flight ground baseline studies, the crew work-rest cycles should parallel the 24-hour earth day for the close time correlation required. The baseline studies should be run under three conditions: (1) Simulated flight, including confinement for a time period equal to the mission length, at ground atmospheric pressure and temperature; (2) the same conditions but with flight atmospheric conditions; and (3) during normal ground operation working conditions. Furthermore, extra samples should be taken at different time periods during the working day over a period of many months in order to establish points of reference should the daily on-board schedule be significantly changed from that used during baseline studies.

The greater the number of samples obtained during the mission, the more meaningful the resultant data will be. There is no magic minimum acceptable number which will guarantee data of a certain confidence level. While one in-flight sample each of blood, urine, feces and sweat is better than no sample at all, the data yield would certainly not be appreciable. Of major interest, physiologically, is the adaptation of man to a new environmental parameter, weightlessness. With more data points available, life scientists will be able to furnish better criteria for weightlessness countermeasures, a regimen of personal hygiene and better design criteria for crew equipment.

Since the interest is focused on experiments, it must be recognized that the validity of results obtained are dependent, in part, upon the frequency with which the measurements called out by the protocols are performed. Furthermore, these experiments deal with small numbers of subjects and there is no assurance that any given experiment or set of measurements will be repeated under the same conditions.

Therefore, the number of times a given measurement is made during the course of an experiments mission must be sufficient to make the data meaningful.

Physiological adaptation, to environmental changes (in this case, to weightlessness) is usually a slow process. By frequent, periodic measurements, the rates of the various changes associated with adaptation of the whole organism can be ascertained. Hematological variations associated with even mild infections can be spotted by doing white counts twice a week. Bacterial and viral infections as well as trends in microfloral shifts have been found by experience to require weekly sampling in order for these phenomena to be well observed. Changes in RBC mass were noted in 1-2 weeks. Bone demineralization has been observed to occur in the same length of time. A survey of experimentalists and clinicians shows that once a week is a reasonable frequency for most of the laboratory analyses.

If this interval between measurements is assumed, let us examine the total sample volumes required from the experiment subjects. Urine is no problem for the tests to be done on-board or post-flight, with some 1200-1500 cc available per man per day. Feces, too, can be collected at each defecation in an amount large enough for all determinations. The sweat test is not much of a problem either.

But, the volume of blood that can safely be taken from a man over a 60-day period is certainly a limiting factor. After determining which measurements should be performed (see Paragraph 4. 2. 2), we find that the total volume of blood that must be drawn to perform each measurement in duplicate once per week, except those comprising the CBC, which are done twice weekly, is 250 cc per man. If samples for the post-flight thyrocalcitonin assay are taken only once every two weeks, the weekly volume decreases to 200 cc and if thyrocalcitonin, which we regard as an important measurement, is dropped, the weekly blood sample volume is 150 cc. In Table 4. 2-5 the volumes of blood required each day for measurements using whole blood, serum and plasma are shown. For a 60-day period, 1200-1600 cc of blood would be taken. A factor to be considered, then, is the amount of blood that can be safely withdrawn without undue effect on plasma volume and RBC mass and, of course, the health and safety of the astronauts.

Wherever possible, micro or ultra-micro methods have been assumed in sizing the blood volumes needed. Even small quantities like 0.05 cc of serum/test or 0.1 cc for the test in duplicate which means about 0.2 cc of whole blood, plus some allowance for that blood which sticks to the syringe and serum which clings to the tube, begin to add up when a large number of tests are to be performed.

Some economies in quantities of blood needed can be effected by R&D on techniques aimed at increasing sensitivity sufficiently to allow volume reductions. The volume required per test, in each case, is the maximum amount for the best analysis for a given constitutent. In many cases, the literature states 0.1-0.3 cc, for example, are needed; the 0.3 cc figure has been used. Thus Table 4.2-5 reflects a worst case. It is extremely difficult, even with clinicians in pediatric practice and their colleagues in clinical biochemistry, to pin down a firm minimum volume of blood necessary for any one test. In clinical practice, accuracy and precision are not considerations of the first rank as they are in research methods because the question to be answered is different, i.e. "Is the patient in the normal range?" vs "Is the subject showing any changes, even in the normal range?"

The experimenters involved must agree on minimum acceptable volumes for analyses which have been thoroughly checked for sensitivity, precision and accuracy (see Section 4.8). Then volumes required for calcitonin (25 cc serum/test), free thyroxine (3 cc serum/test, hemoglobin (2 cc whole blood/test), and prothrombin consumption (3 cc serum/test) can probably be reduced. In addition, samples for serum electrolytes and isotopic mineral metabolism can probably be combined to reduce the total sample required.

Another factor, besides blood volume required, which impinges on measurement frequency concerns expendables. For every sample of blood, urine, feces and sweat, some expendables will be used. The number of expendables per day is shown in Table 4.2-9. The weights and volumes in Table 4.2-10 are estimates based on commercial plastic disposable labware. They total less than 15 lb/per week. Our recommended frequency schedule for the measurements is once per week with two exceptions noted above. If we assume that laboratory development of methods continues to reduce the sample volume necessary for each analysis, the weight of expendables also will decrease.

For example, a 12 cc decrease in the size of a syringe with which to take a sample results in a 15 gram saving in weight/syringe. Similar reductions in storage containers and the like are indeed possible with decreases in sample volume.

The measurement frequency schedule which was finally chosen is depicted in Table 4.2-5. This shows the amounts of biological fluids collected each day of a week. The same sampling schedule is repeated every seven days of a 56-day mission with one exception which is noted. Tables 4.2-6, 4.2-7, and 4.2-8 explain which measurements are done on-board and which post-flight. It also shows which days measurements are performed or samples are taken for post-flight analysis. Except for urine volume, feces wet weight, and return of total dry stool which must be done every day, most measurements are sampled for or performed on-board once a week only. There are two other exceptions to this: a sample is collected for calcitonin analysis (post-flight) once every 14 days; blood morphology, RBC (Total), WBC (Total), WBC Differential, Platelet smear and reticulocyte count are performed on-board twice a week.

Table 4.2-9 lists the numbers of expendables of each type needed each day of the 7-day rotating schedule. It also lists the total number of expendables of each type needed for a 56-day mission. Table 4.2-10 lists launch weight and volume penalties for each disposable and totals for a 56-day mission. Table 4.2-11 lists return volume and weight penalties resulting from the sampling schedules of Table 4.2-5 according to the type of storage required. In this table, feces has been spelled out as a separate item because the GFE device and method for feces lyophilization probably will not dry the feces completely. Therefore, feces, will have to be stored in the refrigerator or freezer to prevent gaseous degradation. If completely dry, it would be possible to store the feces at cabin ambient temperature.

Table 4.2-5. Measurement Frequency Schedule -
Seven Day Rotating Sampling Schedule

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Oxalated Blood		8.0 mL					
Oxalated Plasma		3.5 mL					
Heparinized Blood						10 mL	
Heparinized Plasma						3 mL	
Citrated Plasma							3 mL
Whole Blood with No Anticoagulant	1.2 mL	1.0 mL	4 mL		1.2 mL		
Serum	21.0 mL	16.0 mL		50 mL***		14 mL	
Total Blood Withdrawn*	42.2 mL	48.0 mL	4 mL	100 mL***	1.2 mL	44 mL	6 mL
Urine	46.0 mL	44.0 mL		46 mL	55.0 mL	22 mL	
Sweat							5 mL
Feces	**	**	**	**	**	**	**

*In every case where serum or plasma is required, approximately twice that volume of blood must be withdrawn.

**Volume variable.

***Once every two weeks.

Table 4.2-6. Blood - Seven Day Rotating Sampling Regimen
Tests to be Accommodated

Measurement	Type of Fluid	Volume for Measurement in Duplicate	On-Board or Method of Preservation
Day One			
Bilirubin	Serum*	0.4 ml	Freeze (-20°C)
LDH	Serum	0.2 ml	Freeze (-20°C)
LDH Isoenzymes	Serum	0.2 ml	Freeze (-20°C)
SGOT	Serum	0.4 ml	Freeze (-20°C)
SGPT	Serum	0.4 ml	Freeze (-20°C)
PBI	Serum	0.05 ml	Freeze (-20°C)
Prothrombin Consumption	Serum	6.0 ml	Freeze (-20°C)
Transferrins	Serum	2.0 ml	Freeze (-20°C)
Calcium	Serum	1.0 ml	Freeze (-20°C)
Phosphate	Serum	0.4 ml	Freeze (-20°C)
Cholesterol	Serum	2.0 ml	Freeze (-20°C)
BUN	Serum	0.6 ml	Freeze (-20°C)
Uric Acid	Serum	0.8 ml	Freeze (-20°C)
Alkaline Phosphatase	Serum	0.8 ml	Freeze (-20°C)
CPK	Serum	0.4 ml	Freeze (-20°C)
Immunoglobulins	Serum	1.0 ml	Freeze (-20°C)
Complement Titration	Serum	1.0 ml	Freeze (-20°C)
Antibody Titration	Serum	1.0 ml	Freeze (-20°C)
Parathyroid Hormone (Radioimmune Technique	Serum	0.5 ml	Freeze (-20°C)
Blood Cell Morphology	Whole Blood	0.2 ml	On-Board
RBC (Total)	Whole Blood	0.2 ml	On-Board
WBC (Total)	Whole Blood	0.2 ml	On-Board
WBC Differential	Whole Blood	0.2 ml	On-Board

* In every case where serum or plasma is required, approximately twice that volume of blood must be withdrawn.

Table 4.2-6. Blood - Seven Day Rotating Sampling Regimen
Tests to be Accommodated (Cont)

Measurement	Type of Fluid	Volume for Measurement in Duplicate	On-Board or Method of Preservation
	Day One		
Platelet Estimate (smear)	Whole Blood	0.2 ml	On-Board
Reticulocyte Count	Whole Blood	0.2 ml	On-Board
	Day Two		
Hematocrit	Whole Blood*	1.0 ml	On-Board
Hemoglobin	Oxalated Blood	4.0 ml	On-Board
RBC Mass - DFP^{32} or Cr^{51}	Oxalated Blood	2.0 ml	On-Board
RBC Survival - DFP^{32}	Oxalated Blood	2.0 ml	On-Board
Plasma Volume - RISA	Oxalated Plasma	2.0 ml	On-Board
Total Protein	Oxalated Plasma	1.0 ml	Freeze (-20°C)
Protein Electrophoresis	Oxalated Plasma	0.6 ml	Freeze (-20°C)
Free Thyroxine (T_4)	Serum	6.0 ml	Freeze (-20°C)
Electrolytes	Serum	10.0 ml	Freeze (-20°C)
	Day Three		
Total Body Water	Whole Blood	2.0 ml	Freeze (-20°C)
Bleeding Time	No Sample is Collected	----	On-Board
Clotting Time	Whole Blood	2.0 ml	On-Board
Glucose**	Serum	0.05 ml	On-Board
SGOT**	Serum	0.1 ml	On-Board
Bilirubin (Total)**	Serum	0.1 ml	On-Board
Alkaline Phosphatase**	Serum	0.1 ml	On-Board
	Day Four		
Calcitonin	Serum	50.0 ml***	Freeze (-20°C)

*Heparinized Capillary Tubes should be employed

**Examples of easily flight qualified measurement techniques which will have post-flight backups.

***Once every two weeks

Table 4.2-6. Blood - Seven Day Rotating Sampling Regimen
Tests to be Accommodated (Cont)

Measurement	Type of Fluid	Volume for Measurement in Duplicate	On-Board or Method of Preservation
Day Five			
Blood Cell Morphology	Whole Blood	0.2 ml	On-Board
RBC (Total)	Whole Blood	0.2 ml	On-Board
WBC (Total)	Whole Blood	0.2 ml	On-Board
WBC Differential	Whole Blood	0.2 ml	On-Board
Platelet Estimate (smear)	Whold Blood	0.2 ml	On-Board
Reticulocyte Count	Whole Blood	0.2 ml	On-Board
CPK*	Serum	0.1 ml	On-Board
BUN*	Serum	0.1 ml	On-Board
Lactic Dehydrogenase*	Serum	0.1 ml	On-Board
Protein (Total)*	Serum	0.1 ml	On-Board
Day Six			
Lymphocyte Karyotyping	Heparinized Blood	10.0 ml	On-Board
Fibrinogen	Heparinized Plasma	2.0 ml	Freeze (-20°C)
ACTH	Heparinized Plasma	1.0 ml	Freeze (-20°C)
Blood Lipids	Serum	4.0 ml	Freeze (-20°C)
Mineral Metabolism by Isotopic Techniques	Serum	10.0 ml	Freeze (-20°C)
Day Seven			
Fibrinolytic Activity	Citrated Plasma	3.0 ml	Freeze (-20°C)

*Examples of easily flight qualified measurement techniques which will have post-flight backups.

Table 4.2-7 Urine - Seven Day Rotating Sampling Regimen
Tests to be Accommodated

Measurement	Volume for Measurement In Duplicate	On-Board or Method of Preservation
Day One		
Accurate Urine Volume	----	On-Board
Pyrophosphates	10 ml*	Freeze (-20°C)
Hydroxyprolines	10 ml	Freeze (-20°C)
VMA	8 ml	Freeze (-20°C)
5-HIAA	10 ml	Freeze (-20°C)
Magnesium	4 ml	Freeze (-20°C)
Day Two		
Accurate Urine Volume	----	On-Board
17-Hydroxycorticosterioids	20 ml	Freeze (-20°C)
17-Ketosteroids	20 ml	Freeze (-20°C)
Day Three		
Accurate Urine Volume	----	On-Board

* In all cases, samples will be taken from 24-hour pooled urine outputs

Table 4.2-7 Urine - Seven Day Rotating Sampling Regimen
Tests to be Accommodated (Cont)

Measurement	Volume for Measurement In Duplicate	On-Board or Method of Preservation
Day Four		
Accurate Urine Volume	----	On-Board
Osmolality	2 ml	On-Board
Color	----	On-Board
Specific Gravity	2 ml	On-Board
Glucose	2 ml	On-Board
Protein	2 ml	On-Board
Blood	2 ml	On-Board
Microscopic Exam	2 ml	On-Board
pH	4 ml	On-Board
Bile	10 ml	On-Board
Mucoproteins	0.4 ml	Freeze (-20°C)
Total Amino Acids	2 ml	Freeze (-20°C)
ADH	2 ml	Freeze (-20°C)
Creatine	0.2 ml	Freeze (-20°C)
Creatinine	2 ml	Freeze (-20°C)
Nitrogen	2 ml	Freeze (-20°C)
Calcium	2 ml	Freeze (-20°C)
Phosphorus	2 ml	Freeze (-20°C)
Sodium	1 ml	Freeze (-20°C)

Table 4.2-7 Urine - Seven Day Rotating Sampling Regimen
Tests to be Accomodated (Cont)

Measurement	Volume for Measurement In Duplicate	On-Board or Method of Preservation
Potassium	2 ml	Freeze (-20°C)
Chloride	2 ml	Freeze (-20°C)
Sulfate	0.2 ml	Freeze (-20°C)
Day Five		
Accurate Urine Volume	----	On-Board
Aldosterone	30 ml	Freeze (-20°C)
Mineral Metabolism by Isotopic Techniques	20 ml	Freeze (-20°C)
Day Six		
Accurate Urine Volume	----	On-Board
Catechols	20 ml	Freeze (-20°C) with sodium metabisulphite as preservative
Day Seven		
Accurate Urine Volume	----	On-Board

Table 4.2-8. Feces, Microbiology and Sweat-Seven Day Rotating Sampling Regimen Measurements to be Accommodated

DAY 1 through 7
Accurate Feces Wet Weight - On-Board Return of Total Dry Stool - Drying On-Board; Storage at 4^{o}C or -20^{o}C.
DAY 3, 4, 5, 6 or 7 (Dependent on when astronauts defecate)
N, Ca, P, Na, K, Cl, Mg. - A 20 cc sample of feces from each astronaut must be frozen (-20^{o}C) and stored (-20^{o}C) for post-flight analysis (once each week). Body microflora - 1 cc sample from the stool of each astronaut must be subjected to microbiological culture and preservation (once each week); 5 cc sample from the stool is to be flash frozen and preserved at -70^{o}C.
DAY 7 (Before sweat measurement)
Body microflora sampling and culturing other than feces, and environmental sampling and culturing
DAY 7 (After Body Microflora Sampling)
Sweat Measurement and Sample Return - Volume measurement on-board; sweat and rinse water from astronauts body and underwear is to be pooled and a 5 ml sample is to be frozen (-20^{o}C) and stored (-20^{o}C) for post-flight analysis.

Table 4.2-9. Number of Disposables* for Laboratory Analyses

Item	Day							Total For 56-Day Mission
	1	2	3	4	5	6	7	
50 ml Lymphocyte Karyotyping Culture Container						6		48
Transfer Syringes						18		144
34 ml Syringe						3		24
6 ml Centrifuge Tube Containing Heparin						3		24
3 ml Transfer Syringe						3		24
3 ml Storage Container						3		24
28 ml Centrifuge Tube						3		24
14 ml Transfer Syringe						3		24
14 ml Storage Container						3		24
6 ml Syringe-Tube Containing Citrate							3	24
46 ml Storage Container	3							24
44 ml Storage Container		3						24
20 ml Storage Container				3				24
55 ml Storage Container					3			24
22 ml Storage Container Containing Sodium Metabisulphate						3		24
Storage Containers for Feces	3	3	3	3	3	3	3	168
20 ml Containers for Feces							3	24

Table 4.2-9. Number of Disposables* for Laboratory Analyses (Cont)

Item	Day							Total For 56-Day Mission
	1	2	3	4	5	6	7	
5 ml Containers for Feces							3	24
5 ml Containers for Sweat							3	24
199 H Medium						300ml		2,400 ml
Cellular Fixative						30ml		240 ml
2% Aceto-orcein Stain						30ml		240 ml
42 ml Syringe-Tube	3							24
Microscope Slides and Coverslips	24				24	60		864
Red Cell Pipettes	6				6			96
White Cell Pipettes	6				6			96
Hemocytometer Counting Slides	12				12			192
Lancets	6	3	6		6			63
46 ml Syring		3						24
8 ml Container with Oxalate		3						24
6 ml Centrifuge Tube with Oxalate		3						24
1.5 ml Storage Container		3						24
2 ml Transfer Syringe		3				3		48
32 ml Centrifuge Tube		3						24
16 ml Transfer Syringe		3						24

Table 4.2-9. Number of Disposables* for Laboratory Analyses (Cont)

Item	Day							Total For 56-Day Mission
	1	2	3	4	5	6	7	
16 ml Storage Container		3						24
1 ml Container		18						144
Heparinized Capillary Tubes		6						48
2 ml Syringe-Tube			3					24
Glass Capillary Tubes			15					120
100 ml Syringe-Tube				3***				12
10 ml Syringe						3		24
10 ml Centrifuge Tube Containing Heparin						3		24
Mounting Medium	30 ml				30 ml	30 ml		720 ml
Hematological Fixative	30 ml				30 ml			480 ml
Hematological Stains	30 ml				30 ml			480 ml
Gower Diluting Fluid	18 ml				18 ml			288 ml
2% Acetic Acid	12 ml				12 ml			192 ml
Sheets of Photographic Film	120				120	60		2,400
Dip Sticks for Urinalysis				24				192
**Paper Strips for On-Board Chemical Analysis			24		24			384
**Chemical Pellets, Fluid and Mixing Cuvette for On-Board Wet Chemical Analysis			24		24			384

** Probably a mixture of both
*** Once every two weeks

Table 4.2-9. Number of Disposables* for Laboratory Analyses (Cont)

Item	Day							Total For 56-Day Mission
	1	2	3	4	5	6	7	
Sterile Stick Swabs							15	120
Rodac Plates Containing Blood Agar							42	336
Sterile Swabs	3	3	3	3	3	3	3	168
Disinfect. Fluid Ampule	3	3	3	3	3	3	3	168

*The sizes of most syringes, centrifuge tubes, containers, etc., shown in this chart are not standard commercial items, but were chosen to minimize weight and volume. Use of standard items would markedly increase volume and weight. "Syringe-tubes" are still in the concept stage. They replace 4 separate items all of the same size.

Table 4.2-10. Weight and Volume of Expendables to be Launched

Expendable Item	Weight/ Item Gms	Volume/ Item Cubic cm	Quantity Needed	Totals for 56-Day Mission	
				Weight Gms	Volume* Cubic cm
42 ml Syringe-Tube	50.0	90.0	24	1,200	3,240
Microscope Slides & Cover Slips	3.0	1.0	864	2,592	1,296
Red Cell Pipettes	3.0	30.0	96	288	4,320
White Cell Pipettes	2.0	20.0	96	192	2,880
Hemocytometer Counting Slides	13.0	10.0	192	2,496	2,880
Lancets	0.5	0.3	63	31.5	28.4
46 ml Syringe	60.0	90.0	24	1,440	3,240
8 ml Container with Oxalate	7.0	10.0	24	168	360
6 ml Centrifuge Tube with Oxalate	4.0	10.0	24	96	360
1.5 ml Storage Container	3.0	3.0	24	72	108
2 ml Transfer Syringe	6.0	4.0	48	288	288
32 ml Centrifuge Tube	12.0	40.0	24	288	1,440
16 ml Transfer Syringe	25.0	30.0	24	600	1,080
16 ml Storage Container	7.0	20.0	24	168	720
1 ml Container	3.0	3.0	144	432	648
Heparinized Capillary Tubes	0.5	0.5	48	24	36
2 ml Syringe Tube	6.0	4.0	24	144	144
Glass Capillary Tubes	0.5	0.5	120	60	90

*These volumes include 50 percent of the actual volume of the expendables as a packaging fraction.

Table 4.2-10. Weight and Volume of Expendables to be Launched (Cont)

Expendable Item	Weight/ Item Gms	Volume/ Item Cubic cm	Quantity Needed	Total For 56-Day Mission	
				Weight Gms	Volume* Cubic cm
100 ml Syringe-Tube	100.0	180.0	12**	1,200	3,240
10 ml Syringe	14.0	14.0	24	336	504
10 ml Centrifuge Tube containing Heparin	8.0	12.0	24	192	432
50 ml Lymphocyte Karo Karyotyping Culture Container	80.0	110.0	48	3,840	7,920
Transfer Syringes	4.5	4.0	144	648	864
34 ml Syringe	45.0	90.0	24	1,080	3,240
6 ml Centrifuge Tube Containing Heparin	6.0	10.0	24	144	360
3 ml Transfer Syringe	6.0	4.0	24	144	144
3 ml Storage Container	4.0	4.0	24	96	144
28 ml Centrifuge Tube	20.0	35.0	24	480	1,260
14 ml Transfer Syringe	14.0	20.0	24	336	720
14 ml Storage Container	10.0	20.0	24	240	720
6 ml Syringe-Tube Containing Citrate	10.0	8.0	24	240	288
46 ml Storage Container	20.0	60.0	24	480	2,160
44 ml Storage Container	20.0	60.0	24	480	2,160
20 ml Storage Container	10.0	30.0	24	240	1,080
55 ml Storage Container	25.0	65.0	24	600	2,340

**Once every two weeks.

Table 4.2-10. Weight and Volume of Expendables to be Launched (Cont)

Expendable Item	Weight/ Item Gms	Volume/ Item Cubic cm	Quantity Needed	Total for 56-Day Mission	
				Weight Gms	Volume* Cubic cm
22 ml Storage Container Containing Na Metabisulfate	10.0	30.0	24	240	1,080
Storage Containers for Feces	GFE - Part of Waste Management System				
20 ml Containers for Feces	10.0	24.0	24	240	864
5 ml Containers for Feces	5.0	7.0	24	120	252
5 ml Container for Sweat	5.0	7.0	24	120	252
199 H Medium	1.0	1.0	2,400	2,400	3,600
Cellular Fixative	1.0	1.0	240	240	360
2% Aceto-orcein Stain	1.0	1.0	240	240	360
Mounting Medium	1.0	1.0	720	720	1,080
Hematological Fixative	1.0	1.0	480	480	720
Hematological Stains	1.0	1.0	480	480	720
Gower Diluting Fluid	1.0	1.0	288	288	432
2% Acetic Acid	1.0	1.0	192	192	288
Sheets of Photo. Film	1.0	2.4	2,400	2,400	8,640
Dip Sticks for Urinalysis	1.0	5.0	192	192	1,440
Paper Sticks for On-Board Chemical Analysis	1.0	1.5	384	384	864
Chemical Pellets, etc. for On-Board Wet Chemical Analysis	12.0	12.0	384	4,608	6,912

Table 4.2-10. Weight and Volume of Expendables to be Launched (Cont)

Expendable Item	Weight/ Item Gms	Volume/ Item Cubic cm	Quantity Needed	Totals for 56-Day Mission	
				Weight Gms	Volume* Cubic cm
Sterile Stick Swabs	5.0	15.0	120	600	2,700
Rodac Plates Containing Blood Agar	24.0	18.0	336	8,064	9,072
2,400 Liters 5% CO_2 in Air	---	---	---	***	***
Sterile Swabs	0.1	0.1	168	16.8	252
Disinfect. Fluid Ampule	2.0	3.0	168	336	816
Grand Totals				43,716.3 (96.2 lb)	91,448.4 (3.23 ft^3)

*** Some method of tapping the life support system for CO_2 needed for lymphocyte karyotyping is feasible.

Table 4.2-11. Weight and Volume of Materials to be Returned from OWS to Ground (Resupply Period of 60 Days)

	Weight of Expendables (Gms)	Weight of Biological Material (Gms)	Total Weight (Gms)	Total Volume (Gms)
Storage at 4°C	8,064	- - - -	8,064	9,072
Storage at -20°C	9,120	13,101	22,221	19,656
Storage at -70°C	120	168	288	252
Cabin Ambient	4,800	- - - -	4,800	26,640
Feces	3,360	3,600	6,960	2,400
Grand Totals	25,464	16,869	42,333	58,020

4.3 HEMATOLOGY

Despite developmental difficulties, every effort should be made to perform the hematological sampling and measurements (see Section 4.2.2.1) as a minimum package for initial IMBLMS missions. As future flights are planned and as data from early flights are analyzed and interpreted, a greater number of hematological measurements of increased complexity can be considered.

4.3.1 SELECTION AND RATIONALE

The rationales used for selecting blood tests for IMBLMS flights and rationales as to where the blood tests should be performed (i.e., on-board or post-flight on in-flight samples) are found in Section 4.2.2.1. The hematology of the astronauts is well covered by the measurements chosen. Performance of RBC (total) and WBC (total) every three days is recommended (see also Section 4.2.3): thus, alterations can be spotted quickly from data dumped to ground. WBC differentials should be done every three days also. Changes in profile would yield early information on infections, should they occur, stress and radiation changes. Reticulocyte count will monitor erythropoeisis, while RBC survival will yield information concerning the life-span of erythrocytes during flight.

Hematocrit, hemoglobin, RBC Mass and plasma volume will furnish valuable information concerning space flight affects on these hematological factors, known to have changed on the Gemini missions. Platelet estimates (smear), clotting and bleeding times will give real time fixes on the blood clotting systems in the astronauts while prothrombin consumption, fibrinogen and fibrinolytic activity measurements will give post-flight data on clotting in more detail from in-flight samples. It would seem that this group of measurements more than adequately covers the area of hematology for the projected IMBLMS missions. Of course, later modifications of in-flight sampling and measurements schedules can be made based on the results of early flights.

4.3.2 IMPLEMENTATION

Sampling and measurements in the hematological area present many problems. Major pieces of equipment are necessary, namely a centrifuge, a microscope and a radioactivity measurement device (see Appendix A - Measurement Specification Sheets). It would also be desireable to have a photomicrography attachment for the microscope to permit permanent recording of fields observed in space for post-flight verification. All in-flight measurements necessitate labeling as to source, time, date, and observer. A great deal of time will be needed to train astronauts to become competent technicians in blood sampling and operation of equipment. To make blood counts and to stain and distinguish WBC differentials, would require even more training and competence if astronauts have no medical training (see FFBD'S, Appendix B). All data observed would have to be recorded in appropriate forms and relayed to ground control (see Volume III, data handling). The entire process of hematological sampling and measurement is extremely complex especially when done in a spacecraft (see Human Engineering Work Sheets, Appendix C).

Problems unique to the field of hematology in IMBLMS are:

a. Toxicity and hazard of reagents

b. Radioactivity of labeling solution

The fixing and staining solutions usually used for WBC differential, reticulocyte count, and platelet estimate (smear) are extremely toxic and flammable. They are methanol-based solutions. However, the amount of solutions used for any one determination are very small, less than 30 ml of stain and 30 ml of fixative. One approach is to package the reagents in small amounts in containment devices for preventing spills. Alternately, non-toxic/non-hazardous reagents could be developed with a lead-time of less than two years. Another alternative is phase contrast microscopy which would be very easy to implement and would exact no greater penalties than regular microscopy.

The radioactivity of isotopes needed in determining plasma volume, red cell mass and red cell survival is also a problem.

DFP^{32} for red cell survival and red cell mass is not the best choice because of the short half-life of P^{32}. Extremely large quantities of the isotope would have to be injected pre-flight (possible health hazard) or taken along (heavy shielding and remote handling capabilities necessary) to perform the measurements over a period of 60 days. Some other isotope such as Fe^{59} or Cr^{51} with a much longer half-life might be more appropriate.

4.3.3 DESIGN CONSIDERATIONS

There are three critical environmental parameters which may produce problems in doing hematological measurements in a space vehicle. First, weightlessness causes the most severe difficulties for on-board sampling and measurement. The problem of handling, containing and transferring fluids troublesome. With respec to hematology, these would be injection and withdrawal of samples from closed containers. Because of weightlessness, finger, ear lobe or venipuncture, and blood withdrawal becomes very complicated (see Human Engineering Work Sheets, Appendix C). Every action of the astronaut doing the sampling will produce a reaction in the subject astronaut and vice versa. Both astronauts will have to be physically restrained by devices anchored to the spacecraft. Otherwise, attempts at venipuncture could lead to serious physical damage. For the same reason, all clinical laboratory procedures including sampling will require significantly increased periods of time to perform (as compared to earth-based laboratory times).

The type of gaseous atmosphere employed may also cause problems. Oxygen tension markedly altered as compared with earth normal may seriously alter results of measurements unless control studies performed on the ground prove otherwise. Techniques may require modification to make values obtained in orbit comparable to ground controls.

The same is true of nitrogen tension. In any case, preliminary laboratory testing will be necessary in a ground-based laboratory with the same gaseous atmosphere and pressure as that of the spacecraft.

The atmospheric pressure of the spacecraft may produce severe difficulties with the reagent and sample containers. Unless reagents and sample containers are bottled pre-flight under the pressure used in the spacecraft, spillage may occur when withdrawing aliquots or injecting samples. Containers must be tightly stoppered in case their storage areas are affected by unplanned EVA or pressure changes. Explosions or implosions may result unless this possibility is kept in mind when these containers are designed.

4.4 BIOCHEMISTRY

Biochemical analysis of blood, urine, feces and sweat has been quite widely covered by the list of measurements chosen. Where possible the choice has been directed to on-board methods yielding quasi-real time answers about the effects of space flight on human physiology and as a verification of the sensitivity, precision and accuracy of methods which may be used routinely on interplanetary flights and permanent orbiting satellites for reasons of health and safety. Where in-flight analyses are not yet feasible, samples are to be preserved and returned permitting reliable data to be obtained from post-flight analysis. Because precision and accuracy have been emphasized in the biochemical assessment of the effects of space missions of long duration upon human physiology, the recommended measurement regimen is more research-oriented than operations - oriented in scope and detail.

4.4.1 SELECTION AND RATIONALE

Section 4.2.2.1 gives the rationales for the choice of biochemical measurements as well as reasons for inclusion as an on-board measurement or recommended for preservation and post-flight analysis. Because of the many physiological uncertainties of extended space flight, we would prefer if it were feasible to examine many possibilities. Given restrictions on the amount of biological material available and the power, weight and volume which is allotted for such studies, we have selected from what is scientifically desireable that which is realistically feasible. The resulting list for IMBLMS clinical laboratory evaluation is given in Section 4.2.2.

4.4.2 IMPLEMENTATION

To sample and measure as indicated in Section 4.2 is far from easy. Because of the inherent value of these procedures to the space program, a considerable effort must be made to implement them. Equipment, expendables, training and development requirements are described in Section 4.7.

4.4.2.1 Crew Requirements

Crew requirements for sampling of biological fluids and performing in-flight biochemical measurements are as follows:

a. Sampling excreta in the form of urine, feces and sweat.

b. Separating and preparing portions of these samples for preservation for post-flight analysis.

c. Submitting other portions of these samples to specific in-flight biochemical measurements.

d. Storage of samples to be preserved in appropriate storage devices.

e. Withdrawing blood samples by venipuncture and by finger, toe, heel or ear lobe puncture.

f. Preparing blood samples for preservation and/or in-flight biochemical measurement. This involves such operations as allowing the blood to clot or mixing with anticoagulant, centrifugation to separate serum or plasma from formed elements, separation of serum or plasma from formed elements, etc.).

g. (b) and (c) and (d) above on blood samples.

h. Operation of equipment for performing biochemical analyses such as centrifuge, incubators, calorimeter, microscope, etc.

i. Recording the results (meter readings, counts, etc) of measurements.

j. Communicating the results of measurements to ground control.

The crew-oriented requirements listed above are for the most part self-explanatory. They are stated, however, in general form, and the step by step human engineering breakdowns of each of these tasks may in fact be very complex. (See Human Engineering work sheets, Appendix C.) Taking each requirement separately, we can discuss these complexities to a limited extent.

Category 1 - Sampling Excreta

Collection of specimens of urine and feces may be relatively simple. Various devices to do this automatically have been developed to the prototype stage (e.g., the GE Urine Sampling and Volume Measuring System, NASW-1300). If plastic bags or containers are used, 24-hour pooled urine collections can be made and an aliqot taken. Feces present some difficulty. The problem of separating smaller samples from total output in the absence of gravity may be troublesome, especially from a housekeeping and cleanliness point of view. The use of flexible containers which can be squeezed to mix the sample and to expel parts of their contents through small orifices may be a solution and the sue of syringes is another potential approach. Because of sampling uncertainties, we recommend mass measuring of the total wet fecal specimen, lyophilization and storage.

Collection of sweat presents greater problems. Flexible plastic containers used to surround a limb and collect sweat can be treated as those used for manual collection of urine and feces. To collect the total output of sweat, however, may be difficult, if not impossible, in space. Electrolytes, for instance, can be collected by washing the astronauts' underwear and body surface in distilled water. Some initial plans for collecting and sampling excreta are discussed in the final report of NASA Contract NASW-1562.

Category 2 - Separating and Preparing Portions of Samples for Preservation for Post-Flight Analysis

Preparation for preservation may take the form of adding chemical stabilizers, flash freezing, freezing on a cold-finger, refrigeration, lyophilizing, some combination of these methods or no operation of any kind.

Category 3 - Submitting Other Portions of these Samples to Specific In-Flight Biochemical Measurements

Because of the great variety of different in-flight methods which may be employed, this category is mentioned without description. Discussion of in-flight measurement methodology is discussed elsewhere. Functional flow block diagrams describing these methods and the collection through storage sequence have been prepared, see appendix B.

Category 4 - Storage of Samples to be Preserved in Appropriate Storage Device

This task will probably be straight-forward. It will consist of placing samples in refrigerator, freezer, or a compartment at cabin ambient temperature. One important subtask involved here, is appropriate labeling of the storage containers with astronaut name, source, time of excretion or withdrawal, time of preparation for storage and time of storage.

Category 5 - Withdrawing Blood Samples

This is one of the most sensitive tasks which at least two of the astronauts will have to perform. The health, safety and well-being of the astronauts is involved, and procedures are greatly complicated by the absence of gravity. (See discussion in Section 4.3.3.) In every case, the skin in the area of puncture will have to be scrubbed with disinfectant solution. Syringes, or capillary tubes or micropipetter may be used for capturing samples. Special devices developed for IMBLMS flights may be used in place of, or in addition to these. Withdrawal may be followed by placing the samples in containers for further processing.

Category 6 - Preparing Blood Samples for Preservation and/or In-Flight Biochemical Measurements

Some of the procedures involved in this category are spelled out in the above list. Functional flow diagrams for these have been prepared, see appendix B. The absence of gravity will present special problems, even in such simple steps as transferring samples from one container to another. Special container designs may be required for this reason. Techniques will have to be developed to permit successful performance of all tasks under the condition which will exist in the OWS. (See discussion in Section 4.3.3.)

Category 7 - (b), (c) and (d) on Blood Samples

The only requirement for handling blood which differs from the discussions of Categories b, c and d is the necessity for separating plasma and serum from formed elements and handling or prevention of clot formation. The separation problem may prove very difficult. Centrifugation will separate components, but careful handling of centrifuged aliquots will be

required to prevent remixing. It may be necessary to design a centrifuge tube with valves to separate the components automatically by remote control while the centrifuge is still running.

Category 8 - Operation of Equipment for Performing Biochemical Analyses

A detailed discussion of all the various techniques which will be necessary for in-flight measurements is inappropriate here. Special problems are generated by the absence of gravity and spacecraft atmosphere. Functional flow block diagrams for the devices contemplated for use are found in appendix B. Additional information is found in human Engineering Work Sheets, appendix C. A general discussion of critical environmental factors is found in Section 4.3.3.

Category 9 - Recording of the Results of Measurements

Category 10 - Communicating the Results of Measurements

These data handling categories are discussed in Volume III.

4.4.3 DESIGN CONSIDERATIONS

Design considerations are similar to those discussed under hematology; see Section 4.3.3.

4.5 CYTOLOGY

Despite the difficulties produced by the decision to do karyotyping on-board, provisions for the requirements and planning for the training, implementation of new techniques and devices should be made because of the highly essential nature of the information gained. Data on the mutagenic qualities of space flight and space radiation will permit the design of spacecraft for longer future missions.

4.5.1 SELECTION AND RATIONALE

If cytological techniques for studying reticulocytes, leukocytes and platelets are excluded, the only measurement in the NASA list which falls under the general category, cytology, is lymphocyte karyotyping. This is as it should be, because methods used for obtaining human tissue samples other than blood for cytological and cytochemical analysis, involve tissue biopsy which would be painful and dangerous in any spacecraft in orbit.

Hematological stains used for reticulocytes, leukocytes and platelets are those commonly used for cytological examination in the clinical laboratory. The possibility exists, however, for doing quantitative cytochemical anlyses for enzymes, RNA, DNA, lipids, etc. Fine structure could be examined if fixation, post-fixation treatment and staining for post-flight electronmicroscopy were performed on blood samples. This possibility can be no more than that for the time being. Fine cytochemical and electron microscopic preparative methodology is extremely exquisite, involves many hazardous or toxic reagents, some hazardous procedures and an enormous amount of finesse. At the present time, feasibility exists only for some preparative steps, i.e., fixation and storage for later processing and staining. It may, in fact, be possible to make a few extra smears of blood cells to fix and store them for post-flight cytochemical examination. But no further on-board cytological techniques other than those for WBC differential, reticulocyte count and platelet estimate are recommended at this time.

The above arguments also hold ture for lymphocyte karyotyping. The techniques involved in doing karyotyping immediately after blood withdrawal or in preserving leukocytes for cultures at a later time are difficult, time consuming and require considerable skill. Chromosomal abberations and anomalies, however, are an excellent means of ascertaining radiation exposure. In fact, karyotypes have been called biological radiation dosimeters. Although space flight itself may produce karyotype changes, the synergistic effects of weightlessness and radiation are the major unknowns. For these reasons, every effort must be made to include lymphocyte karyotyping in the measurement list for every IMBLMS flight.

It could be argued that, even though karyotyping is important, lymphocytes could be more easily preserved for post-flight culturing and analysis. The point is well taken. But it is our opinion that karyotyping should be done on-board during the course of each mission because the results may be important in deciding whether a mission should continue. Dr. Michael Bender, ONL, Tennessee, who is principle investigator for the IMBLMS "Cytogenetic Study" (M111) agrees with this point of view. In the event that the frequency of chromosomal anomalies reaches or surpasses some predetermined maximum permissible frequency, the spacecraft would have to be recalled in order to assure crew health and safety. This concern with health and safety is a major argument for developing the capability to do lymphocyte karyotyping on-board. On-board performance is feasible, with about a two-year lead time for flight-qualified hardware, and is therefore recommended.

4.5.2 IMPLEMENTATION

The techniques for culturing lymphocytes, like many tissue culture methods for mammalian cells, are very complex. The method used by Dr. Bender calls for withdrawal of 2.5 to 5 ml heparinized whole blood, separation and withdrawal of the buffy coat (thin layer of leukocytes and platelets which occurs between the plasma and the erythocytes when a blood sample is centrifuged), placing the cells in a medium composed of serum (can be of human or animal origin), 199H tissue culture medium, phytohemagglutinin, penicillin and streptomycin.

The culture is then incubated at 37°C for three to four days. Because the medium is buffered with bicarbonate, 5% CO_2 in air must be bubbled through it continuously. (A container incorporating a semi-permeable membrane such as cellophane and exposed to the gas micture described could perform the same function in the absence of gravity.) At the end of the culture period, colchicine or other mitotic poisons are added to the culture and incubated for a few hours.

The cells are then harvested, smeared on microscope slides so that the metaphase chromosomes are spread out and separated, fixed and stained with aceto-orcein (phase microscopy may be a possible alternative). The well separated groups of metaphase chromosomes are then mounted by adding cover slip and mounting medium on the slides, and the slide is examined under a microscope. Groups of chromosomes of the appropriate types (it takes skill to choose them) are photographed using the highest magnification (90-100X oil immersion objective, 10-20X eye-piece, with resulting magnification of 1,000X-2,000X). Resolution needed is that found in the better research microscopes.

If the total procedure, from drawing of blood to first stage data reduction could be done on-board, the following sequence would occur. The photographic negatives are developed and enlarged prints (8" x 10") are made. Each chromosome from a single metaphase cell is cut out of the prints, pairs are matched, examined for anomalies and scored. The technique described in the last sentence takes a great deal of skill. Dr. Bender estimates that it would take him two months to train a biologically unskilled astronaut to an adequate level of competence to perform this task. As all the other tasks he feels he could train an astronaut to do them in two weeks. We feel that he is overly optimistic in estimating these training periods. He is, however, working on a device which would do the first phase of the analysis automatically using a computer with small memory (50K core) and reducing the data to approximately 200 words per karyotype which could be transmitted from spacecraft to ground. Dr. Bender concurs with the estimate that a flight-qualified device could be developed within two years, given the necessary effort and funding.

When the analysis of the karyotype is complete, the results, including identifying information, must then be relayed to the astronauts to ground control. In the case of the automatic device, a telemetry dump of the 200 words would be necessary from the computer with all the appropriate identifying information (see Section 3, Data Management, Volume III).

If all data handling is to be performed on the ground, two alternatives exist, both of which rely upon spacecraft-ground TV transmission. (See Volume III, Section 3.9 for discussion of TV). The TV camera could be used for sending images of microscope fields directly to the ground where pictures could be taken, cut, chromosomes paired, and scoring done by a scanning device. A TV camera could also be used to transmit images of enlargements of microscope fields made on-board, with ensuing data reduction done on the ground.

4.5.2.1 On-Board

Equipment required for on-board measurement includes centrifuge, incubator (37°C), microscope with photographic attachment. Provision must be made for 5% CO_2 to be passed over perm-selective membranes in culture vessels (in concept stage). Small amounts of CO_2 are involved here and pose no safety problem. It might be possible to generate the CO_2 needed, from the life support system. If an automatic device for karyotype measurement and data reduction is not available, provision would have to be made for producing photographic enlargements of cell images. It might be possible to do this with a properly adapted on-board microscope, but an on-board photo-processing capability would be required.

4.5.2.2 Post-Flight

Preservation of leukocytes for post-flight karyotyping is a less complicated procedure but may well be even more expensive from an engineering design point of view. A 2.5 to 5 ml heparinized whole blood sample is withdrawn and centrifuged. The buffy coat is again separated out. It is then added to 199H Medium. Glycerol is added to make up a final concentration of 10-15% (dimethylsulfoxide is an alternative); this mixture is then

allowed to stand for 10 minutes at room temperature. Next, the mixture is frozen at the rate of $1^{o}C$/minute starting at 20-25^{o}C until a final temperature of -30^{o}C is reached. The container with the frozen mixture is then stored at -70^{o}C or lower (Dr. Bender uses liquid nitrogen). This procedure has no discernible effect on the viability and mitotic yields of lymphocytes cultured after preservation according to Bender; no differences have been seen in the karyotypes produced without preservation and those with it, but a rigorous test of this hypothesis is necessary before the preservation approach can be accepted as valid.

He feels that it would take him only two weeks to train an unskilled astronaut to perform the techniques required for preservation, but this, too, may be overly optimistic.

For on-board karyotyping, see FFBD's, Appendix B, Measurement Spec. Sheets, Appendix A, and Human Engineering Work Sheets, Appendix C.

4.5.3 DESIGN CONSIDERATIONS

See Section 4.3.3. The design considerations of critical environmental parameters is discussed at length for hematology in the section noted. The same restrictions are involved in doing karyotyping. The additional problem exists in that a liquid medium requires incubation for three-four days.

4.6 MICROBIOLOGY AND IMMUNOLOGY

There are two areas which microbiology/immunology procedures for IMBLMS should investigate:

a. Health and Safety of the Crew

b. Epidemological and Scientific

Equipment, technical limitations, training and experience, time demands, and sensitivity of the methods necessary to accomplish the first objective in a manner consistent with obtaining meaningful results have been reviewed. It was concluded that diagnostic capabilities cannot be supported by on-board operations. The depth necessary to meet the information demands for accurate, reliable medical decision-making is beyond the capacity of the technical capability which can be made available in IMBLMS. Significant shifts in microbiological populations can occur in a closed ecological system. These shifts could be potentially dangerous to the crew, but it is virtually impossible to predict in advance what changes to anticipate or what counter-measures to institute. Realistic preparation for these eventualities are possible only if carefully controlled, ground-based studies are conducted. Semiautomated devices for viral immuno-agglutination or fluorescent antibody detection of bacteria are considered to be basically unsuitable. Objections such as questionable sensitivity, reagent shelf-life stability, high specificity requirements, and difficulty in interpretation strongly argue against employing these techniques in-flight. We are dealing with exceptionally healthy adults. A quarantine of the spacecraft, pre-launch, might alter the requirement for information needed for real-time medical decisions.

In-house studies have been performed on the development of a semiautomated device which will stain bacterial organisms for on-board examination (e. g. Gram stain). It is felt that this capability would provide a measure of information for medical decisions.

If specific information for medical decision-making is desired, the number of clinical determinations possible in the areas of microbiology and immunology is staggering.

Gradwohl's Clinical Laboratory Methods & Diagnosis, (Ref. 1) Volume 1, details 459 pages of information on bacteriological, cirological and immunological tests, including 34 bacterial stains available for use, not to mention special stains for capsules, spores and flagella. From Gall, (Ref. 2, 3, 4) Rosebury (Ref. 5) and others (Ref. 6, 7) several lists of microorganisms important to health and safety have been compiled; an array of some 20 genera of bacteria and 9 specific viruses (5 types) have been suggested as important markers for identification purposes (see Table 4.6-1).

Table 4.6-1 Twenty-five Microorganism, Potentially Pathogenic for Spacecraft Crew

Bacteria	Viruses
Staphylococcus aureus	Adenovirus (types 3, 4, 7)
Streptococcus pyogenies (Group A)	Reovirus (Echo 10)
Streptococcus viridans	Rhinovirus (Echo 28)
Diplococcus pneumoniae	Coxsackie virus (A & B)
Clostridium perfringens	Myxovirus influenza (A_2 & B)
Corynebacterium diphtheriae	
Neisseria meningitidis	
Haemophilus influenzae	
Fusospirochetal organisms	
Bacteroides funduliformis	
Escherichia coli (polyvalent path. serotypes)	
Pseudomonas aeruginosa	
Proteus species (polyvalent antisera)	
Klebsiella pneumoniae	
Salmonella (Groups A, C, C_1, C_2, D, & E)	
Shigella (Groups A, B, C, &D)	
Candida albicans	
Actinomyces israeli	
Nocardia asteroides	
Mycoplasma pneumoniae	

Valid arguments could be advanced for the inclusion of additional candidates or for the exclusion of others on this list. No matter what the final choice, reliable identification of these organisms by on-board procedures would require an enormous array of reagents, instruments, and other hardware. Any set of choices would depend, ultimately, on chance. If reliable information for real-time medical decisions is to be provided, then sufficient alternatives in testing procedures must be available.

For these reasons, immunological and microbiological investigations for IMBLMS will be limited to:

a. Epidemiological - Routine collection of samples from crew and cabin areas, followed by preservation, and post-flight analysis by ground-base laboratories.

b. Scientific - Practical experiments which will provide new scientific information and specific answers for future long-term manned flights.

In a closed, ecological system such as a spacecraft, indigenous microorganisms can undergo a number of modifications: Some of the microflora may die out entirely. Other species will, in time, dominate, either to the benefit or detriment of the crew members. Sudden shifts in the population could be precipitated by an overt bacterial infection in one of the crew. The consequences of such an event are unpredictable. Since information on the effects of these biological interchanges within a closed system is not now available, such testing must be conducted in the pre-launch period.

If the epidemiological and scientific objective is considered, a program like that which follows must be implemented:

a. Pre-launch preparations must include a careful analysis of all microflora indigenous to each crew member, along with a comprehensive program of immunological procedures. Determination of what may constitute potentially "dangerous" organisms to the mission can, and should be made at that time, and appropriate action taken, e. g. :

1. Replacement of "dangerous" crew member(s) with back-up astronauts.

2. Antibiotic therapy to eliminate suspected organism(s) before launch date.

b. Pre-launch program for the actual spacecraft must include the following as minimum precautions:

1. Reduction of personnel entering and leaving the living quarters of the craft to a minimum beginning at least one to two weeks before launch.

2. Control of essential personnel to minimize additions to the microflora within the spacecraft. Measures such as sterile protective outer garments, including shoe protectors, disinfection of tools, thorough washing of hands, etc., must be rigorously enforced.

If the above program is instituted, there should be no need of real-time microbiological testing of astronauts for health and safety reasons.

It is thus recommended that all microbiological and immunological testing be performed post-flight on in-flight samples. In the case of bacteria and fungi, a short in-flight incubation prior to storage at 4° C will be required.

4.6.1 SELECTION AND RATIONALE

4.6.1.1 Bacterial Identification

4.6.1.1.1 Isolation - According to Gradwohl, (Ref. 1) the most important principle of bacterial identification is the necessity of working with pure culture -- "It is well-nigh impossible to correctly identify mixed cultures." Picking colonies to achieve a pure culture involves time-consuming steps and a certain amount of expertise. Also implied is a variety of culture media needed for selective transfer, the time required to re-grow the selected colonies, and the subsequent transfer to selective media. Selection, isolation and identification leads to a rather formidable pyramiding of subcultures with consequent heavy demands of time and space.

4.6.1.1.2 Fluorescent Antibody Detection (FA) - This method probably lends itself better than any other to possible automatic instrumentation with a minimum of manual demands. Nevertheless, reliable and accurate results depend upon the following:

a. Presence of sufficient quantities (approximately 10^3-10^4 organisms) of type-specific bacteria to elicit a detectable response to specific, labeled antibody.

b. Determination of background fluorescence; and conversely, provision for the possibility of naturally occurring materials within any given sample which might absorb fluorescence (quenching) thus masking results. Normal testing procedures call for pre-processing of specimens to reduce these contaminants to a minimum.

c. Stability of the labeled antibody reagents. In order to assure a reasonable versatility and capability, a rather large variety of these reagents would be necessary, all of which may not possess the same degree of shelf-life stability over a given time period.

d. Reliable interpretation of results. The subjective nature of viral readout, due to cross reactions, non-specific staining, and quenching especially with unprocessed, raw samples requires considerable training and experience. Automatic machine sensing may not be sufficiently discriminating for reliable performance.

4.6.1.1.3 Staining Methods - This represents the most practical approach but can only produce crude bacterial identification. Although an automated method for applying 5 reagents (simple Gram stain) to a slide, through a timed sequence, and under zero-G conditions requires considerable development, such a device is feasible. The development and qualification could be accomplished with a lead time of from 12 to 18 months. Therefore, straining is a subject for study and development for possible late IMBLMS add-on.

4.6.1.2 Viral Identification

Isolation of any viral particles from an apparently healthy individual is an extremely difficult task (and a very unlikely event) even with the full resources of a well-equipped laboratory. Successful isolation during an overt viral infection is dependent upon the time at which the appropriate sample is taken, i.e., during the extracellular phase of replication when virus is actively being shed.

4.6.1.2.1 Isolation

The most sensitive method of visual identification is through tissue culture isolation methods. However, the problem of growing and maintaining a stock of tissue monolayers under space flight conditions has not been studied. Since virus particles are specific in their affinity for cells, tissue stocks from more than one source would have to be provided and maintained. Subsequent identification of any virus isolated would still be dependent upon selective inhibition following titration against a battery of purified, specific antibodies carried as stock reagents. Large numbers of reagents and equipment are required. Laboratory procedures take much time. The training (tissue culture is still more of an art than a science) requirements are excessive. There is small chance for any positive results.

4.6.1.2.2 Viral Immuno Agglutination

An imaginative approach to specific viral identification has been suggested through the use of antibody-sensitized "beads." (Ref. 8) The process depends upon the agglutination, caused by a specific antigenantibody reaction between the known antibody which is coated on the bead, and the corresponding virus particle in the unknown sample. The clumps which form, assuming the specific viron is present, are counted as they pass through a modified Coulter Counter orifice which is adjusted to disregard the smaller, unclumped beads as background noise. It is very unlikely that the sensitivity of this method is low enough to detect any virus, even in a small percentage of tests. In addition, relatively pure, high-titered antibody for many virus groups is very difficult to produce (e.g., adenovirus, coxsackie). Some virus groups, such as coxsackie, have many types (24 Type A, 6 Type B) for which no common antigen is known. Therefore, a very large number of partially purified, high-titered antibody-coated beads would be needed to provide sufficient versatility for immunoagglutination.

4.6.1.3 Immunological Methods

Immunological techniques in general are useful for determining the presence of either antigen or antibody. The common factor for a majority of classical serological procedures is the need for a variable number of serial dilutions to determine the highest dilution (or lowest concentration) which is capable of eliciting a positive response.

At the present time, a practical technique for processing liquid dilutions is not feasible for use in space and is likely to remain unfeasible for at least 2-3 years. The methods are time consuming, and require a large variety of reagents.

Serological procedures will be performed post-flight on preserved samples. A list of the commonly employed serological tests is described below:

a. Complement Fixation (CF) - This is the most sensitive in terms of the amounts of antibody/antigen which can be detected. On the other hand, it is one of the most difficult to perform. Successful execution of the CF test depends upon standardization of four variables (hemolysin from rabbit serum, complement from guinea pig serum, sheep red blood cells, and standardized antibody or antigen). These are titrated against a fifth variable (unknown antigen or antibody).

b. Hemagglutination (HA) and Hemagglutination Inhibition (HI) - These titrations are employed for the presence of antigen or antibody in suspected virus infections. This is particularly true where a myxovirus is suspected, although HA activity has been detected for other viruses (adenovirus, measles). A supply of suitable, fresh red blood cells is required since the reaction is dependent upon attachment of the virus particle to a specific site on the red cell (or inhibition of attachment). Numerous dilutions are required for each sample, also.

c. Serum Agglutination - Primarily a bacterial antibody assay, this titration depends upon the formation of clumps as the result of agglutination in serially diluted solutions of unknown antibody mixed with a standard quantity of antigen. End points are determined visually by holding each dilution in a ray of oblique light and rating the amount of agglutination as 0 through 4+. Since the antigen-antibody reaction is specific, large numbers of standardized antigen preparations would be necessary in order to provide versatility.

4.6.1.4 Immunoelectrophoresis

While this technique shows promise for eventual space flight use, the identification of microbiological antibodies by on-board equipment is not feasible at this time. Samples must be purified before use, and there are large power requirements.

4.6.1.5 Radioautography

With radio labeling, sensitivity is increased up to 2 to 3 orders of magnitude over immunoagglutination or fluorescent antibody.

However, serious problems emerge with the choice of the isotope; soft emitters such as C^{14} present a minimum of radiation hazard, with a concomitant reduction in shielding required. But, to achieve accuracy and precision with low numbers of organisms, extremely long counting periods (several hours to days) would be required. For more rapid results, the hard emitters, such as potassium or phosphorus, may be employed, but radiation danger and shielding requirements go up accordingly.

4.6.2 IMPLEMENTATION - MICROBIOLOGICAL SAMPLING

Actual sampling for presence of viable bacteria, fungi, and viruses will be done on each crew member and specified cabin area once every seven days. For meaningful information, samples for each individual and surface area should be taken as close together as time and conditions permit. Data from these isolations will allow comparisons of the microflora to be made along with possible interpretations as to microbial population shifts. Table 4.6-2 shows the areas to be sampled, equipment needed, action required and final disposition of samples.

4.6.2.1 Procedures

4.6.2.1.1 Bacteria and Fungi

A. Medium - In order to conserve space and weight, only one medium, commercially prepared Blood Agar, will be used for all bacterial and fungal sampling. Rodac plated will be pre-poured with fresh blood agar medium immediately before flight and sealed until needed in air-tight containers to prevent moisture loss through evaporation. Sterile, plastic bags from which air has been evacuated will contain enough Rodac plates, either per bag or in multiples, to satisfy the requirements for each sampling period.

B. Sampling Periods - Eight weekly samples will be required. In addition, pre-launch samples, gathered as near to lift-off as is practical (before bathing), will also be required. These will include the same body areas as specified in Table 4.6-2 as well as a final sample from the work surface and personal hygiene area. These cabin samples should be obtained just before the vehicle is closed to begin the count down routine. It is very important that pre-launch samples be taken in order to insure good baseline data for comparison purposes.

Table 4.6-2. Schedule of Microbiological Sampling Areas, Frequency and Method of Handling

Sample Site/Area	Frequency	Sample Method	No. Used	Incubation		Time (hr)	Final Disposition
				Aerob	Anaerob		
Feces	1/week	Swabs	2	1	1	48	Save at 4°C
	1/week	5 ml aliquot	1	-	-		Flash Freeze & store at -70°C
Naso-pharynx	1/week	Swabs	2	1	1	48	Save at 4°C
	1/week	Swabs (Virus sample)	1	-	-		Deposit tip of swab in 3 ml of diluent, flash freeze & store at -70°C
Axila	1/week	Rodac Plates	2	1	1	48	Save at 4°C
Groin	1/week	Rodac Plates	2	1	1	48	Save at 4°C
Toes	1/week	Rodac Plates	2	1	1	48	Save at 4°C
Work Surface	1/week	Rodac Plates	2	2	-	48	Save at 4°C
Personal Hygiene Area	1/week	Rodac Plate	3	3	-	48	Save at 4°C
Cabin Air	1/week	Rodac Plate with modified sieve-type sampler*	1	1	-	48	Save at 4°C

*Requires further study

As mentioned earlier, routine samples from body areas during the flight must be obtained as close together as is practical. It is anticipated that immediately before personal hygiene periods will be the optimum time. Samples from each body area should be made in successive order on each crew member.

C. Feces Sampling - One feces sample per man per week will be assayed for bacterial and/or fungal growth. These samples from each individual should be gathered the same day, if possible. It is not necessary to take feces samples at the same time body areas are sampled.

The procedure is as follows: the tips of two moist swabs per sample, are drawn through the fecal material, making certain that, if the bolus is solid, the swabs break through the outer layer. Each swab is rolled lengthwise over the surface of the agar in a Rodac Plate. One plate is incubated aerobically at 35°C and the other under anaerobic conditions at 35°C for 48 hours and transferred to the 4°C storage area.

D. Naso-pharynx - Two moist swabs are rubbed over upper and lower gums on the left side of the mouth, under the tongue and then rolled over the hard pallate as far back in the mouth as possible. Material on each swab is transferred to Rodac plates as described for the feces samples, and incubated under aerobic and anaerobic conditions for 48 hours and stored as above.

E. Axilla - Two Rodac plates each, in succession are pressed firmly onto the skin for 10 seconds, just under the left armpit, then recovered, incubated and stored as above.

F. Groin - The area just below the crotch, on the inside of the left leg are sampled by firmly pressuring for 10 seconds with two Rodac plates and incubating and storage as before.

G. Toes - The big toe of the left foot is held apart and the Rodac plate rolled firmly in the area between the toes as far as possible. Part of the agar surface can be used to press down on the ajacent toe-area. Incubate and store as above.

4.6.2.1.2 Viral Sampling

A. Feces - This can be taken at the same time as the bacterial/fungal sample is obtained. The 5 ml container is filled with fecal material, flash frozen and stored in the -70°C freezer.

B. Naso-pharynx - A moist swab sample is obtained exactly as described in the bacterial procedure. The tip is then broken off as close to the swab-end as possible and dropped into the special vial containing 3 ml of a 50% glycerol solution. The container is recapped and the entire contents flash-frozen and stored in the -70°C freezer.

4.6.2.1.3 Work Surfaces and Personal Hygiene Areas

One Rodac plate for each of the five surfaces to be sampled are pressed firmly on the prescribed area. Plates are incubated for aerobically only for 48 hours and then transferred to the 4°C refrigerator area for storage.

4.6.2.1.4 Air Sampling

We are considering the design of a modified sieve type air sampler to be used at the same time the body areas are sampled. Incubation would be aerobic only with storage at 4°C as above.

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4.7 R&D REQUIREMENTS

There are five main areas where research and development efforts are necessary. First, the development of equipment, i.e., major pieces of hardware must be started early so that flight qualified hardware will be available by the earliest possible flight date. Next, expendables will require redesign and development to keep weight and volumes minimal and for flight qualification. Third, methods used in-flight for collection, preservation and on-board measurement must be carefully worked out so that the feasibility of their use is proved. Fourth, the effect of all the environmental parameters which will exist in the OWS and which can be simulated on the ground, upon the normal levels of all parameters to be measured must be carefully evaluated in order to distinguish the effects of spaceflight itself. Last, the actual astronauts who are to be used on an IMBLMS mission must be studied pre- and post-flight to get a firm fix on the normal levels and ranges of fluctuations of all the parameters studied.

4.7.1 EQUIPMENT

All equipment proposed must be designed within the power, weight and volume constraints of the spacecraft. Chief items of hardware necessary are centrifuge, refrigerator, freezer ($-20^{o}C$), freezer ($-70^{o}C$), incubator ($37^{o}C$), microscope, photomicrographic attachment, spectrophotometer, and densitometer attachment, and a radioisotopy sensor. Not only must the usual procedures for the development of flight qualified hardware be followed for all of the equipment needed but in addition, prototype hardware must be made available for the training of the astronauts for IMBLMS missions. This "use-testing" should precede flight qualification because modifications may be necessary.

4.7.2 EXPENDABLES

Many of the expendables described in Section 4.2.3 are not standard (e.g., "syringe tubes"). They require the same type of developmental program as that for equipment. Materials must be sought of low density which at the same time meet NASA requirements for low toxicity and flammability. It is possible that large savings in weight and volume can be

achieved by such a development program. The only limits on such a program are time and money. If research and development for IMBLMS expendables is begun soon, the effort invested in the devices (mentioned in Section 4.2.3) will realize significant savings. It is also necessary that prototype expendables be available for astronaut training in IMBLMS procedures. Again, the "use-testing" should precede flight qualification procedures.

4.7.3 IN-FLIGHT AND POST-FLIGHT METHODOLOGY

4.7.3.1 Collection and Preservation

Many potentially troublesome areas exist in the collection-preservation sequence. Blood withdrawal, separation of plasma and serum, separation and storage of feces samples and separation and storage of urine samples are all problems. The consequences of all the operations involved in these tasks under zero gravity conditions must be anticipated and resolved. Laboratory testing of such procedures must be performed over and over again under various conditions of simulation until techniques which are acceptable are found. These procedures must be formally adopted by NASA and written out in detailed SOP's.

4.7.3.2 Measurements

After preliminary establishment of specific biochemical techniques for in-flight measurements, all such techniques must be verified in experimenters' laboratories and limits of accuracy, sensitivity and precision must be determined. These limits will be checked by double blind studies. If, during this period, any specific technique proves not feasible because of complexity, lack of precision or any other reason, a new technique must be developed and verified in a similar manner or the measurement must be dropped from the in-flight list.

During this initial test period, NASA and Experimenters will accept specific techniques when they are satisfied of their feasibility for in-flight use. SOP's will be generated for each technique.

A second period of pre-flight testing of specific techniques will follow a schedule developed for sampling and measurement for each IMBLMS flight (60-day periods) in a mock-up of the OWS (in the gaseous atmosphere and pressure to be used for flight) with prototype or flight qualified IMBLMS equipment. All techniques to be used will be repetitively tested following the schedules to be used in-flight. Subjects employed should be the astronauts themselves or men of similar age, training, experience and health, who have received the same training as the astronauts for bio-chemical and sampling techniques. Any techniques which do not prove feasible for any reason during this period must be further revised or discarded.

All biochemical techniques to be used on-board should be incorporated in the preliminary laboratory verification test plans as outlined above to test and evaluate their feasibility for in-flight use.

Techniques employed on IMBLMS flights or, for that matter, in the pursuit of any scientific proof, must be sensitive, precise and accurate enough to demonstrate variation if it occurs. It is not just the question of whether or not a specific measurement lies in the "normal range", which might be sufficient if the only concern were, "Is the astronaut sick or well "

The data will be used to develop trends yielding predictions related to mission extension. For this reason, measurement techniques must be especially accurate, precise and sensitive, much more so than those used in routine hospital clinical laboratories.

4.7.4 EFFECT OF ENVIRONMENTAL VARIABLES ON IMBLMS MEASUREMENTS

Good experimental design requires the study of the effect of all the spacecraft environmental variables other than "weightlessness" upon healthy, adult males for a period at least as long as that of the IMBLMS mission.

All variables which can be simulated on the ground including gaseous atmosphere, pressure, temperature, humidity, flight suits, flight schedules, confinement areas, etc., should be built into a series of chamber runs upon groups of test subjects as similar as possible to the astronauts themselves (if astronauts are not available as subjects). Without such rigorous pre-flight control studies, it may not be possible to distinguish changes produced by space flight. These chamber runs should be performed, as a minimum, pre- and post-flight. In addition, for both elegance and excellence of experimental design, there should be a chamber run, using the backup crew, concurrent with each IMBLMS flight.

In chamber studies concurrent with and post-flight, the methods employed must be identifical to those used in-flight. Even the equipment used for sampling and measurements should be prototype or backup flight qualified hardware. Where in-flight samples are stored for post-flight analysis in chamber runs, the methods and storage equipment must be the equipment of those which are used in flight. Samples analyzed "post-flight" from chamber runs must use the same handling methods and measurement techniques used for flight samples.

For all post-flight analyses of in-flight samples, the effectiveness of the preservation technique chosen must be checked out in the laboratory using the techniques to be employed on actual flight samples. Alterations of preservation method (e.g., temperature) must be done repeatedly for substances whose concentration is observed to change during storage, and/or standard curves of degradation must be generated so that the original concentrations of the sample can be predicted from any value after X days of storage. This would involve testing of samples every week after initial storage for 70-80 days for every substance on the "preserve" list. In order that families of curves can be generated for most possible initial values, at least ten different initial concentrations of substances in biological fluids (varying from below the normal range through the normal range to above it) should be followed through the period. At least five different technicians, preferably from the actual experimenters' pool, should perform every measurement using a NASA established technique in duplicate

or triplicate throughout the period of storage in the actual laboratories that they will use for post-flight analysis. In cases where returned samples are to be flown to geographically separate sites for analysis, this same procedure should be used for each determination during the pre-flight testing period. The entire processing procedure which will be employed for returned flight samples should be used for each determination during the pre-flight testing period.

4.7.5 PRE- AND POST-FLIGHT ESTABLISHMENT OF ASTRONAUT BASE-LINES

Any endeavor which is to have scientific merit must have proper controls. Present protocols state that astronauts are to be studied for baseline determinations for a period of 15 days before and 15 days following any given IMBLMS flight. This period may be inadequate to determine baselines adequately. To achieve experimental objectives it may be necessary to study the crew for periods equal to the flight duration, both pre- and post-flight. The hour of the day measurements and sampling are done is also extremely important. Most physiological parameters, for example, follow a circadian cycle. Thus, a measurement and sampling schedule, like that used in-flight should be followed throughout the pre- and post-flight period. Rest, activity and eating schedules should also be identical.

4.7.6 R&D REQUIREMENTS FOR MICROBIOLOGY AND IMMUNOLOGY

Rigidly controlled, ground-based studies under simulated space flight conditions are also essential to the successful implementation of the microbiological and immunological phases of the IMBLMS program. Preparation for potentially dangerous or emerging situations and maximum extraction of data from the samples taken are possible only if control studies are included by the experimental design as part of the pre-flight routine. Adequate foreknowledge of the following are needed:

a. Effect of high oxygen tension (3.5 - 3.9 psia) and reduced cabin pressure (5 psia) on the growth and maturation of bacteria and fungi.

b. Possible effects of alterations or shifts in the microbial population over a 60-day flight on the well-being of the crew. Although a few short term studies of this type have been attempted, the effects of longer confinement together with space-

craft atmosphere and pressure are unknown at this time. Obviously, in order to draw valid conclusions, a parallel or sequential study of identical length, but with "normal" or everyday pressure and atmosphere is needed. Only if the effects of these variables are firmly established can the effect of zero gravity be studied and useful conclusions drawn following the initial IMBLMS flight.

c. Effect of possible therapeutic measures, such as "re-feeding" of a bacterial species which was lost, or no longer detectable during the course of the flight. Another very very important measure is the effect of an antibiotic regimen and the potential emergence of a drug resistant species.

d. Effect of the antibody profile of each individual as mediated by the so-called antigenic -stimulus-deprivation. The actual amount of post-flight immunological assays will be limited to the number or micro-titrations possible with approximately 1.0 ml of serum/sample. Knowledge of what antibodies may or may not be identifiable would greatly facilitate actual space flight analysis. It should be noted here that although the ground studies using the actual crew members would be ideal, it is recognized that this may be impractical. However, use of other members of the astronaut population is preferable to non-astronaut subjects even though some could be obtained with well-motivated volunteers.

e. The effectiveness of the projected training program for flight personnel can be studied. Unexpected difficulties or increased capabilities would be discovered and at the same time actual flight hardware and techniques could be evaluated.

f. Practice sessions with other IMBLMS measurements would establish possible time overlaps or technical conflicts at a stage when remedial action can still be taken.

Useful and reliable scientific data will be obtained only if the proper ground controlled studies are carried out. Biological entities, such as bacteria, fungi, and viruses are influenced, as is man, by many variables. Data obtained on these microorganisms will represent the sum total of their response to all of these variables. Therefore, the known variables should be regulated as closely as possible in order that intelligent conclusions and predictions can be obtained.

It is recognized that such studies are expensive to institute. More important, they are difficult and tedious to set-up and operate properly in terms of suitable well-motivated "crew members" and thorough attention to details. If the term "scientific" is to be applied to IMBLMS, the necessity of doing controlled studies must be recognized as a vital link in a successful experiment chain.

4.8 DATA QUALITY

The philosophy underlying the approach taken by the General Electric Company is that we must assure that analytical results will yield the best data possible in terms of physiological significance, accuracy, precision, and sensitivity. The need for good physiological data is self-evident: extended weightlessness may result in changes in the physiology of astronauts which may be deleterious either temporarily or permanently. Little information is available with regard to physiological changes which may take place in the course of space flight. All that we know is the result of before and after studies for the relatively short periods of the Gemini missions.

Regardless of which measurements are made on-board and which on the ground post-flight, each measurement and each analysis should meet these criteria:

a. Physiologically significant
b. Accurate
c. Precise
d. Sensitive

By physiological significance of a measurement, we mean that a measurement yields useful information regarding some specific physiological variable. The physiological significance of any given measurement is admittedly difficult to determine. Yet, the sampling of subjective opinions of a number of physiologists and clinicians has shown considerable agreement on the rank order of importance of groups of measurements (see Tables 7-6 and 7-7 in the Final Report on Collection and Preservation of Biological Specimens, Contract No. NASW156 and Tables 3-7, 3-8, 3-9, and 3-10 in the Phase B IMBLMS Final Report).

Accuracy is defined as the difference between a measured value and the true value of some variable. It is often very difficult to determine true values, however, and in clinical tests for blood, sweat, urine and feces, it is frequently impossible. Determination of accuracy usually consists of comparing results using a given method with those obtained using a referenced method which is generally accepted. When evaluating new methods, a technique

sometimes employed is to add a known amount of the substance of interest to a test sample and determine how much is recovered.

Precision is the variation of results when a sample is measured over and over again; a synonym for precision is reproducibility. This is a major source of error in doing the clinical tests discussed in this report. The precision noted on a number of test procedures refers to error when the test is repeated by the same person in the same laboratory within a short period of time. But when precision is measured between different people in different laboratories, the results may be so bad that significant differences in test values would be undetectable.

Sensitivity is defined as the minimum quantity of a substance which can be detected by a given analytical method for that substance. Highly sensitive methods are, of course, desirable. Substances which occur in very low concentrations require analytical methods of high sensitivity, but substances which are found in high concentrations do not require highly sensitive techniques. It must be remembered, however, that the sensitivity of a method is a determining factor in being able to distinguish between concentrations which vary only slightly. In most cases of this kind, the precision of a method will be the final limiting factor unless sensitivity is very poor.

Whether a measurement be biological, physical or chemical in nature, the three attributes of sensitivity, accuracy and precision are necessary in order to obtain data of good quality. For biological measurements, we must add the attribute of physiological significance.

The last one, unfortunately, cannot be quantified. The others, though, for the most part, can be quantified in measurements which would be characterized as biochemical. The hematological measurements do not lend themselves to measures of accuracy or sensitivity, although precisions of a rough order of magnitude can be calculated. The same is true of cytological observations which are expressed numerically as in karyotyping. Microbiology is still more art than science, and, although results can be expressed numerically, it is extremely difficult to obtain measures of accuracy and precision. In Immunology, we have the requisite of great sensitivity but often lack those of accuracy and precision. Thus, from

the standpoint of the biologist, measurement techniques and methodology leave a great deal to be desired. This does not mean that every effort must not be made to obtain precise, accurate data with methods of high sensitivity, but it does mean that we often fall short of our goal. Prior to start of work on Contract NASW-1562, a Study of the Collection and Preservation of Biological Specimens During Space Flight for Post-Flight Analysis, NASA defined, in response to our question, standard laboratory accuracy as that which would fall within the range of $\pm 5\%$. We have extended the 5% figure to also include the limits of precision. These limits are in keeping with common practice in all good research laboratories. The 5% limit is used because the data then fall within the 95% confidence level.

Although the experiments to be performed during IMB LMS flights will have a small number of subjects, there will be enough data points, it is hoped, so that some statistical treatment of the data can be made. Thus limits are required if this data is to be used with reliability as a basis for decisions on whether or not man can withstand the rigors of extended space flight.

In the physical sciences, the National Bureau of Standards meets the needs for supplying a system of standards or known quantities that can be used for comparison. The success of our missile and space program offers testimony to the accuracy of today's instruments. There is no National Bureau of Standards for biological measurements. Instruments used in making biological measurements usually have greater precision and accuracy than the measurement itself, because the accuracy of test standards varies from $\pm 1 \times 10^{-2}$ to $\pm 1 \times 10^{-11}$.

It is extremely difficult to make reliable decisions from unreliable measurements although, in some cases, if our measurements are not as precise and accurate as we would like them to be, we can still base reliable decisions on them, thanks to statistical methods. It must be remembered, though, that statistics, too, has limitations; statistics can be overused, and often is, to explain away data of very poor quality. There is an old saying, "Figures don't lie, but liars figure". Statistics has its place, but with data of good quality, namely data obtained from measurements which are sensitive, precise and accurate, statistics then becomes an aid in establishing ranges and deviations and assists greatly in interpretation of the data, and is not used as a whitewash for bad data.

In Appendix E is a reprint of a paper, A Scheme for the Comparison of Quantitative Methods, which is reprinted by permission of the copyright owner, The Williams and Wilkens Company, from The American Journal of Clinical Pathology. The reprint states in part: "This scheme was developed as part of the program of the Standards Committee of the College of American Pathologists in response to the need for a statistical method by which new diagnostic products could be evaluated. It was found to be so satisfactory for this purpose that it was presented in a form which permits a more general application. Although the discussion and examples are chosen to reflect a clinical laboratory orientation, the scheme is equally applicable to many non-clinical types of quantitative analysis. In brief, the scheme uses a number of simple statistical tools by means of which a quantitative method of analysis (test method) can be evaluated in a single laboratory by comparison with a reference method. The reference method may be the one currently employed in the laboratory or a different one thought to be more suitable...."

Although this paper certainly uses statistics which are simple in nature, it is a very definite step in the right direction. For the preliminary laboratory verification test plans, the procedure specified in this paper would suffice as a first step. In addition, we recommend that double-blind studies also be used to ascertain the efficacy of a given analytical procedure.

The double-blind procedure was instituted some years ago for the purpose of clinically testing new drugs. The method is quite simple: medication is dispensed to some patients and placebos to others. The patients, of course, do not know what they are receiving and neither does the physician administering the medication. All such drug trials use doseages which are coded and known to a third party. Only after the results are in is the dispensing physician advised of the identity of the compounds administered to the patients involved.

Double-blind studies can be used for laboratory test verification of clinical laboratory procedures by using quantities of serum or urine which have been pooled. Aliquots can be sent to several laboratories for testing while the reference laboratory runs the analysis or analyses in question on the original pool of serum or urine. As an added check, known quantities of a given substance can be added to the serum or urine to insure that the range or amount of the

substance in question is well outside of that considered normal. Analyses for many compounds can also be tested in this fashion by simply disolving soluble compounds in water or an aqueous solution of polyvinylpyrolidone which has been recommended by a number of clinical chemists for addition to water blanks in order to simulate more of the physical properties of blood. By using a combination of aqueous solutions, pooled serum which has been checked in a reference laboratory by at least two methods for a given substance, plus aliquots of pooled serum to which has been added a known amount of the substance in question, the accuracy, precision and sensitivity of any given biochemical technique can be determined.

The techniques used in each of the participating laboratories should be (a) the method under test; (b) the reference method used by the laboratory conducting the verification; (c) another method used in a particular laboratory which may or may not be the same method used by one or more of the other participating laboratories. The samples should be coded, as should the results obtained from each of the techniques used in each of the laboratories involved. After statistical treatment of the data is completed, the source of the data, sample content, and technique name can be identified for inter-method comparisons.

The results from such a double-blind study can then be treated statistically to determine the accuracy and precision of methods when run by one operator or more than one operator. Thus a measure of inter- and intra-operator error is also obtained and statistical treatment of the results can be done to obtain a good measure of precision.

If a more sophisticated statistical treatment is desired then that shown in the paper contained in Appendix E, methods such as least means squares or regression analyses can be used. For that matter, it would be well to do, both by study and laboratory work, a determination of just what degree and amount of statistical treatment is required in order to thoroughly verify each and every biochemical technique.

Hematological procedures do not lend themselves to measures of accuracy. However, an index or measure of precision can be obtained not only for the method but also as a reference point for the intra- and inter-technician variation in performing a given procedure upon a given sample of blood.

Since the samples which will be returned for non-quantitative measurements will be mostly in the form of slides, it would be well for those technicians who will be performing these determinations post-flight to have this measure determined so that post-flight data may be properly evaluated.

Microbiological data does not easily lend itself to precision and accuracy measures. The stumbling block here, is that there is yet no known way to obtain from the same site successive samples which are identical in nature. Immunological procedures can be quantified to an extent, but the state-of-the-art is not yet advanced enough to allow us to place the desired amount of stress on precision and accuracy, but rather we must accept the sensitivity along with some measure of precision as the best available at this time.

A point which must be made concerning data quality is that whether the method of analysis be categorized as macro, micro, or ultramicro, a major error which can be introduced is in the aliquoting of the sample used for any given analysis. For macro tests, using one cc of sample, an error of 0.05 cc will cause an error of some 5% (assuming all other factors are equal). However, when we go to the ultramicro range, which uses samples measured in microliters, an error of 0.025 cc in a sample requiring 0.05 cc causes an error of 50%. Thus, one of the major considerations of data quality is the sample size used for any specific measurement, and this in turn is dependent not only upon the design of suitable equipment and expendables, but also upon operator skill and motivation.

It is evident, therefore, that a very carefully planned program of measurement selection, technique development, astronaut training, and motivation of astronauts is required if data of the best quality is to be obtained from the IMBLMS measurements.

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SECTION 5

BEHAVIORAL MEASUREMENTS

5.1 SUMMARY

In the process of completing the preliminary survey of available procedures and instrumentation for the measurement of behavior, it was established that:

a. No single instrumental or procedural approach currently exists, which could provide quantitative information on a continuous basis regarding modifications in baseline behavioral status.

b. No formal methodology has been established for the identification of specific behavioral parameters that should be considered for measurement in the unique circumstances in question namely, "The assessment of a carefully selected, highly trained astronaut's behavior during orbital operations."

c. There exists a huge plethora of generically similar measurement areas with an equally enormous selection of measurement approaches, each of which has its unique following that decries all other approaches.

d. There are only a limited number of experimenters who have consistantly utilized a fairly formal technique and instrumental approach in situations wherein the data generated was directly applicable to space operations or where the possibility of transposability or extrapolation to orbital operations was feasible. Unfortunately, most of the techniques developed required extensive manhour expenditures, relatively large volumetric, mass, power or expendable material loads, or while adequate for providing an index of a unique behavioral function, did not have the flexibility or breadth of application required for the IMBLMS multi flight, multi vehicle approach.

e. Many of the current operational approaches using "artificial" operations or procedures, extensive straight forward psychiatric analysis, the administration of extensive (single administration) questionaires or the evaluation of outputs from performance in inadequate or inappropriate simulational situations was met with great resistance and in some cases overt rejection on the part of the individuals under measurement.

As a result of the preceding the General Electric Company implemented, a "tops down - multi thread analysis" to identify, trace and substantiate areas of behavioral measurement as a function of:

a. The possibility that stressors or other effectors inherent in the physical and operational surroundings of orbital operations could reasonably be expected to alter the behavioral mode selected.

b. The sensitivity or criticality of the behavioral measure selected was of such critical import to program or survival success that monitoring its status during early prolonged orbital residence was deemed manditory if for no other reason than to demonstrate its stability.

The list of behavioral characteristics to be measured was then analyzed in order to develop techniques and instrumentational approaches that could be utilized to provide reliable and quantitatively expressed data while meeting as closely as possible all of the constraints imposed by potential inclusion in an orbital spacecraft cabin.

The work described provided the following:

a. A series of selected behavioral measurement areas.

b. An organization of these measurement areas under the generic headings supplied by NASA for guidance to demonstrate the potential coverage and cross correlational possibilities provided by the selected measurements.

c. A listing of recommended measurement/instrumentation/techniques utilized for gaining the selected measures. This listing also identifies the area which will have the prime responsibility for providing the hardware for the measure as well as a demonstration of the high degree of cross correlation, or multiple application of the measurement techniques finally selected for inclusion.

Each of the selected measures decided upon is described in detail in respect to its formal program related Definition, Rationale for inclusion, Utility of derived data, Measurement techniques available in IMBLMS and general commentary as indicated. This Description and Details are discussed in the remainder of Section 5. 0.

5.2 SELECTION GUIDELINES

5.2.1 INTRODUCTION

In an effort to delineate meaningful and justifiable measurements of human behavior in an orbiting spacecraft, GE implemented an extensive literature search and conducted a series of discussions with several individuals in industry and Government who had made meaningful contributions to the area. In correspondence from John W. Senders, currently associated with MIT; Brandies University; Bolt, Barenik and Newman; and others, Mr. Senders summarized part of the problem most succinctly. His Statement Follows:

> "The major problem which arises with respect to manifestations of emotional disturbance, character or personality change is that the measuring instruments available for these are weak and generally unreliable and difficult to validate. I, personally, know of no paper and pencil or other easily transportable tests from which it can be said that prediction can be made with good statistical accuracy and little residual variance on the basis of test results. In addition, most of the instruments used are not designed to test minor deviations from what might almost be called hypernormals but rather to detect extreme deviations from population norms."

In addition to this lack of availability and/or sensitivity of emotional measures the problem that so many differing procedures have been used, each in such a highly restricted circumstance that very frequently there is little or no basis to transfer or to extrapolate material to the spaceborne reference. To a very large degree, in those areas of psychological/behavioral/performance measurement where quantification has occurred, the instrumentation or operational procedure utilized is inappropriate for utilization in the constraints of a spacecraft.

The General Electric effort consisted of a "tops-down analysis". This concept, which will be explained in detail later, is based on the assumption that the behavioral aspects of interest would be directly related to possible modification by residence in the orbital spacecraft or by their innate criticality to successful high level human phychomotor or cognitive performance.

The IMBLMS Program is directed at providing the instrumentation and operational procedures necessary for the measurement of human behavior on-board orbiting spacecraft. In order that this may be accomplished, it is essential that those areas of human behavior requiring measurement in the spacecraft environment be identified. As a result, an attempt was made to delineate and organize areas of stress or unique conditions that were directly identified with the environment assumed to be present in an orbiting spacecraft. Five basic generic areas were identified. These conditions provided the point of departure.

After extensive analysis, consultation and review of all pertinent materials, six basic criteria were developed against which the inclusion of any given measure could be assessed. Measurements of man's behavior in the space environment must be accomplished in order to:

a. Identify and develop quantitative measures which describe manifestations of human behavior in the space environment.

b. Identify and quantify trends towards modification of human behavior which could compromise either mission-related performance or survival.

c. Develop measures and techniques which would permit the correlation of behavioral modification to etiologies manifest in the space environment.

d. Establish quantitative limits of acceptable human performance.

e. Develop techniques that would permit prognostic decisions regarding probability rates of development and the associated implications of observed behavioral change to mission or survival critical activities.

f. Provide a quantitative basis for evaluating and establishing desirable behavioral characteristics for future crew selection and training criteria.

This analysis assumes a worst-case. An attempt was made to pin-point and identify all possible parameters in orbit that were potentially capable of modifying human behavior. No assumptions were made as to whether the modifications were beneficial or degrading. This is not meant to imply that the authors anticipated the manifestation of these changes in every instance, but rather that they felt it necessary to insure the fullest possible description of the area under scrutiny in order to guarantee the most flexible and complete measurement capabilities possible with the maximum instrumental economy.

5.2.2 APPROACH

The IMBLMS Program is dedicated to providing a complete and flexible measurement capability in the behavioral area. Any attempt to instrument all potential measurements and all potential instrumentation commonly available to the ground-based experimentor was completely beyond feasibility.

The approach utilized for the present study based its measurement selection on the following:

a. Measurements should be taken on those parameters of human behavior which could be reasonably assumed to be subject to modification by the unique characteristics present in the orbiting spacecraft.

b. Measurements should be taken of those critical human behavioral characteristics which, while currently assumed to be stable, could if moderately deteriorated, compromise the crew's safety or performance potential.

c. All measurement areas selected for inclusion should be capable of being measured and expressed in terms of quantifiable values with instrumentation and procedures which could be reasonably assumed to be feasible for the circa 1971 state-of-the-art.

d. All measurement practices selected will be capable of being so configured as to permit their repeated application during the mission in order that data may be developed describing the rates of on-set or pin-point the appearance of specific phenomena as a function of elapsed orbital residence time.

Finalized hardware design configurations and operational procedures for behavioral measurements, while possessing a capability for simultaneous implementation with other measures, will have enough instrumentational independence to permit their exclusion and/or replacement with new measures without compromise to the rest of the modularized system.

5.2.2.1 Developmental Program

The following developmental program was instituted and implemented (see Figure 5.2-1).

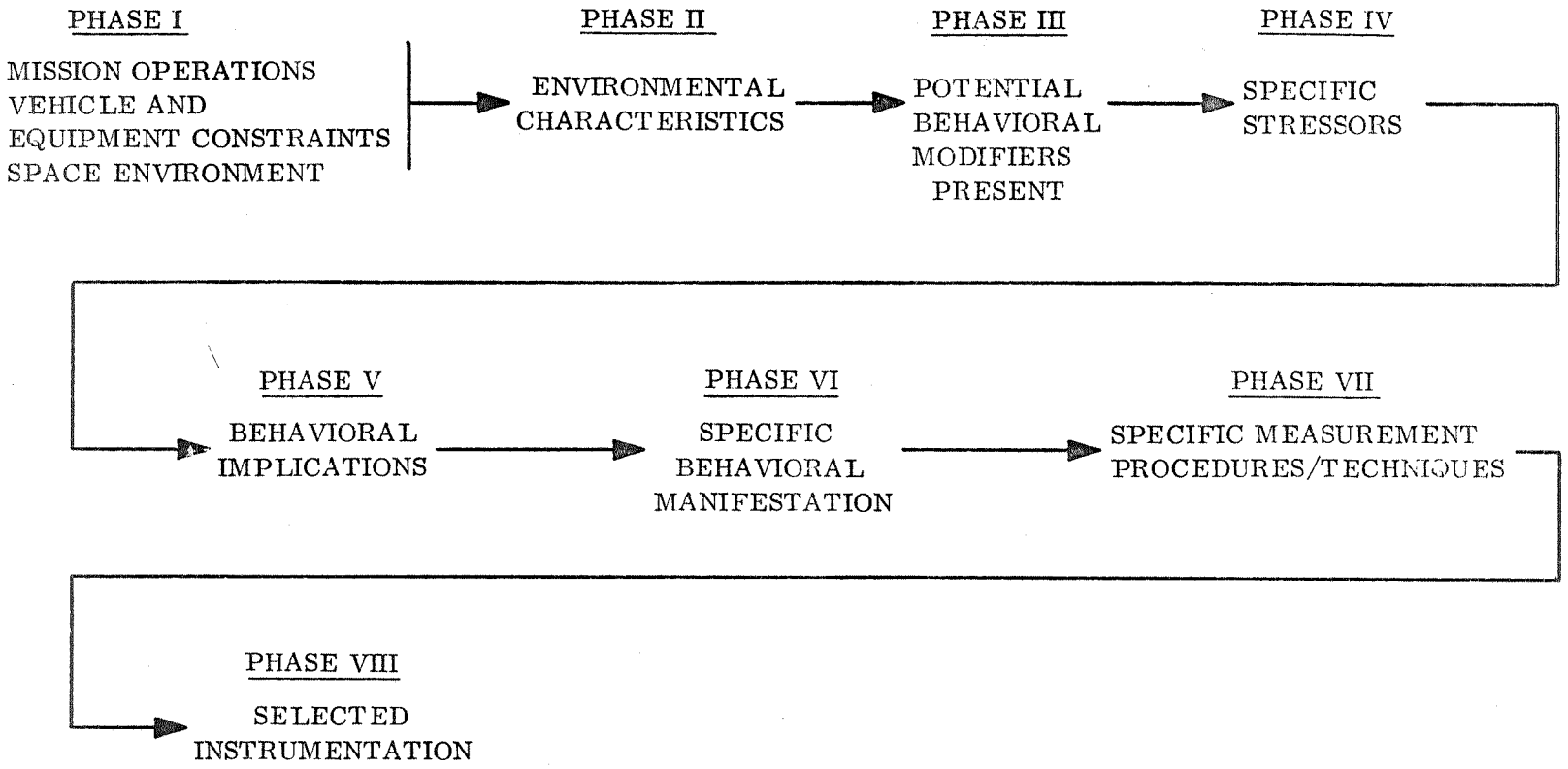


Figure 5.2-1. Developmental Program

Phase I

Three primary areas of the spacecraft contribute to the potential modification of human performance. The three areas were:

a. Mission operations

b. Vehicle and equipment constraints

c. The space environment

These three areas dictated the environmental surround, and provided the basis for Phase II of the analysis.

Phase II

In Phase II, the three areas were separated into six characteristics of the orbital spacecraft environment capable of inducing behavioral modifications as a function of a specific unique stressor circumstance. The six characteristics were:

a. Prolonged residence in a multi-manned closed ecological system

b. Residence in a high hazard environment

c. Weightlessness

d. A 24 hour/7 day work profile (extended continuous operations)

e. High notoriety

f. Mission Operations

In the following analysis, Items 1 through 5 were considered independently in respect to their impacts on behavior. Item 6, while possessing an unquestionable effect on human performance, is at present insufficiantly defined for inclusion in the current effort. As soon as identification is available, this characteristics will also be developed.

Phase III

During Phase III (see Tables 5.2-1 through 5.2-5) each of the five basic characteristics were independently analyzed for the "Potential Behavioral Modifiers" assumed to be present as a function of the characteristics in question.

Phase IV

The potential behavioral modifiers were in turn examined in order to delineate the "associated latent stressors" identified as contributing to the behavioral modification.

Phase V

Each of the latent stressors then were examined in order that the "Behavioral Implications" of each could be identified and evaluated.

Phase VI

These implications were converted into "Specific Behavioral Manifestations" that could initiate or sustain inadequate or inappropriate behavior.

Phase VII

During Phase VII, "specific measurement procedures/techniques" were delineated which would provide reliable, quantifiable and pertinent data regarding the presence, development and general status of those behavioral modifications or manifestations. The measurement procedures and techniques were evaluated in respect to:

a. Their feasibility for space flight implementation

b. The quality and quantity and pertinence of the data they produced

c. Their flexibility in application in respect to the possible cross correlation of collected data, and finally

d. Their capability to insure coverage and assessment of those areas of human performance where deterioration might compromise crew safety or mission function.

Environmental Characteristics:	Potential Behavioral Modifiers Assumed To Be Present	Associated Latent Stressors:	Potential Behavioral Implication:	Possible Overt Behavioral Manifestations
Prolonged Residence In A Multi-Manned Closed Ecological System	Severe Extended Physical and Social Group Isolation/Confinement	Lack of Privacy Forced Physical and Social Interaction Loss of Physical Access To Emergency Aid Forced Celibacy Modification of Normal Work/Rest/Relaxation Cycles a. Content b. Timing (Sequence, Chronology, Duration) Monotony (Work, Surround, Diet, Companionship, etc.) Increased Reliance On Personal and Group Skills Possible Changes In System Microecology Altered Circadian Stimulus Environment Limited Crew Size Operational Schedule Dictating a. Personal Contacts Rather Than b. Personal Selection	Changes In Intra-Goup Behavior Changes In Mission-Related Motivation Levels Changes In Emotional/Personality Adjustment Changes In Manifest Anxiety Changes In Overt Behavior/Performance Changes In Arousal Levels/Time Changes In Motivational Direction Changes In Fatigue Levels	Loss Or Modification In Group Cohesiveness Increased Overt Manifest Aggression Modification in Emotional Lability Modification in Irritability Thresholds Modification in Mission-Related Activation Level Redirection of Activation Objectives Secondary Physiological/Behavioral Indications of Anxiety Responses Changes In Command Structure Stability Or Configuration Modifications In Work And/Or Cognitive Performance Effectiveness Changes In Circadian Response Profiles Modification Or Overall Gross Psychomotor Potential Modified Metabolism And Correlated Concomitants (Arousal, Etc.) Changes In Vigilance/Arousal Levels And Chronological Profile Of Same
	Limited Intra-Vehicular Open Volume	Lack of Privacy Forced Physical and Social Interaction Limited Gross Movement Limited Work And Storage Volumes	Changes In Intra-Group Behavior Changes In Group Behavior Modifications In Gross Motor Performance	
	Artificially Maintained, Survival-Critical Environment	Changes In System Microecology Survival Dependence On Continued ECS Operation Possibility Of Cumulative Effects On Basic Physiology Or Performance Continuous Monitoring For Survival Insurance	Possible Physiological Changes With Secondary Effects Of Such Activities/Phenomena As: Appetite, Digestion, Metabolism, Excretory Function, Etc. Increased Anxiety Possible Performance Degradation	

5/9/10

Table 5.2-1. Potential Behavioral Modifier Matrix

Possible Overt Behavioral Manifestations	Behavioral Parameters Selected For Measurement	Technique
Loss Or Modification In Group Cohesiveness	(1) Croup Cohesiveness	Self-Administered Questionnaire (1, 2, 3, 4, 7)
Increased Overt Manifest Aggression	(2) Personality Stability	Remote Interview (1, 2, 3, 4, 7, 10)
Modification in Emotional Lability	(3) Emotional Adjustment/Lability	Intra-Crew Communication Monitor (1, 2, 3, 4, 6, 7, 9, 10)
Modification in Irritability Thresholds	(4) Activation - Level & Direction	Remote Performance Monitor (1, 2, 3, 4, 5, 6, 7, 9) a. TV Observation b. Telemetry Material Regarding Control Inputs To Complex Tasks
Modification in Mission-Related Activation Level	(5) Gross Psychomotor Performance	Photometric Data Collection Of Performance Of Gross Motor Tasks (5)
Redirection of Activation Objectives	(6) Gross Assessment Of Circadian Constancy	Analysis Of Personal Diary, Flight Log, Annotated Flight Time-Line, Formal Post-Flight Debriefing (1, 2, 3, 4, 6, 7, 10)
Secondary Physiological/Behavioral Indications of Anxiety Responses	(7) Anxiety Levels & Modes of Manifestation	Formal Measures Of Physiological Correlates Of Anxiety (6, 7, 9) a. 17 Ketosteroids b. Eosinophiles c. Sleep Profiles d. Sweat e. Body Temperature f. Heart Rates g. Respiratory Rates & Volumes h. Metabolism i. Blood Pressure j. Body Weight k. Hand Steadiness
Changes In Command Structure Stability Or Configuration	(8) Inter-Personal Relationships (I.E., Command Structure, Communication Routes Or Modes, Work Effectiveness, Etc.)	Measures Of Arousal Via (4, 6, 7) a. EEG b. Vigilance Test Procedures c. Eye Movement Monitor/Blink Rate
Modifications In Work And/Or Cognitive Performance Effectiveness	(9) Measurement Of Vigilance/Arousal Profiles	Short & Long Term Memory Assessment
Changes In Circadian Response Profiles	(10) Measurement Of Cognitive Function	
Modification Or Overall Gross Psychomotor Potential		
Modified Metabolism And Correlated Concomitants (Arousal, Etc.)		
Changes In Vigilance/Arousal Levels And Chronological Profile Of Same		

Environmental Characteristics	Potential Behavioral Modifiers Assumed to be Present	Associated Latent Stressors	Potential Behavioral Implications
High Hazard Environment	Survival Threatening Conditions in the Space Surround a. Vacuum b. Radiation c. Temperature d. Micrometeorite Impact e. Acceleration f. Dangers Attending Orbital Reentry through the Atmosphere g. Hostile Action h. ECS System Failure i. Biomedical Failure with no Professional Facility or Aid j. Post-Landing Recovery k. Isolation l. Exotic Contamination m. Effect of Psychiatric Failure of One Crew Member on Remaining Crewmen n. Primary Effects of Weightlessness on Performance o. Secondary Effects of Weightlessness on Physiology p. Mechanical On-Orbit Failure q. Launch Failure r. Pressure Suits Failure s. Absence of Circadian Stimuli t. Abnormal Atmosphere Artifically Maintained u. Hazardous Mission Operations	Anxiety Regarding Potential Physical or Psychiatric Injury/Death Anxiety Due to Possible Mission Failure Due to Disablement Possible Degradation or Loss of a Psychomotor, Psychosensory, Cognitive or Survival Critical Function Due to Direct Exposure to a Stressor	Loss or Degradation of a Sensor Motor, Cognitive or Survival Critical Function by Direct Act of a Stressor or by Secondary Effects Developed by Prolonged Exposure to High Level Anxiety Modification in Mission Orient Activation Modification in Emotional and Personality Baselines

5-11/12

Table 5.2-2. Potential Behavioral Modifier Matrix

Possible Overt Behavioral Manifestations	Behavioral Parameters Selected for Measurement	Techniques
Changes in Psychosensory, Psychomotor or Cognitive Functions Increased Manifest Anxiety Stress Induced Modifications in Physiology Loss of One or More Mission Critical Functions Due to Direct Injury Imposed by Contact with a Hazard Altered Emotional or Personality Structure Changes in Levels and Direction of Motivation with Greater Emphasis on Safety/Survival Challenge to Command or Mission Protocol in the Implementation of High Hazard Tasks	(1) Emotional Stability (2) Personality Stability (3) Anxiety Levels and Modes of Manifestations (4) Absolute Measures of Selected: - Sensory Function - Motor Function - Cognitive Function (5) Activation Levels and Direction (6) Group Cohesiveness (7) Stability of Command and Communication Functions (8) Modification in Task Performance Potential	Interview Via TV-Audio Link (1,2,3,5,6,7) Post-Flight Analysis of (1,2,3,5,6,7) a. Personal Diaries b. Self-Administered Questionnaire Quick Time and Post-Flight Analysis of Content, Routes, Etc. of Crew Inter-Communication (1,2,3,5,6) Periodic Measurement of (1,3,4) a. Visual Function b. Auditory Function c. Vestibular Function 1. See Neurological d. Proprioceptive/Kinesthetic e. Neuromuscular Integrity 1. Strength 2. Endurance 3. Reaction Time f. Arousal g. Cognitive Function 1. Memory 2. Decision Making/Problem Solving (Symbolic Reasoning) 3. Arithmatic Task/Time-Line Analysis (1,3,5,8)

Environmental Characteristics	Potential Behavior Modifiers Assumed to be Present	Associated Latent Stressors	Associated Latent Stressors (Cont)	Potential Behavioral Implication	Possible Overt Behavioral Manifestations
Weightlessness	Absence of Gravitationally-Developed "Energy Sinks" or "Force Platforms" Absence of "Weight" as a characteristic of Mass Absence of Gravitationally-Induced Compressive Friction Absence of Gravitational Compression Along the Longitudinal Aspect of the Human Skeletal Structure Absence of Gravitationally-Induced Acceleration, Orientational Aligments, Stabilization or "Weight" Based Displacement Absence of a Gravitationally-Based "Up" - "Down" Organization	Disruption in "Origin/Insertion" Relationships of Musculature Severe Modification in the Capability to Generate and Transmit Kinetic Forces Without Artificial Restraint Modified "Biological Energy Expenditure" to Accomplish Work, (i.e., Acceleration and Deceleration Impulses to Move or Position a Mass as Opposed to Sustained Energy Expenditure Until Mass Returns to Mechanical Support) Modified "Afferent Feedback" From Kinesthetic Receptors During Movement as Well as During Maintenance of a Static Posture Absence of Parabolic Trajectory for Objects in Free Flight Absence of Adquate Longitudinal Force Vector or Compressive Stimuli for Physiological Homeostasis a. Cardiovascular Orthostatic Corrections b. Labyrinthine Alignment Absence of Frictional Stabilization in "Seated" or "Standing" Posture for Force Emission Platform	Ballooning of Clothing and Other "Draped" Fabrics or Flexible Materials Inappropriateness of "Walking Concept" in an Upright Position as a Form of Locomotion Loss of Normal Convection Currents in Atmosphere or Liquids as a Function of Temperature Gradients Reliance on Visual Cues for "Up - "Down" Orientation Indefinite Duration of Dispersion of Particulate Material in Cabin Atmosphere (Unless Removed) via Forced Draft Filtration Susceptibility to Agravic Illusion During O-G Onset Altered Cardiovascular Profile (Due Adaptation to Hypodynamic Environment and Loss of Hydrostatic Head) May Cause Modifications in Circulation	Requirement for Artificial Stabilization or Restraint at "Origin" Aspect of Musculature for Normalization of Muscular Coordination Modification in the Amplitude and Time Course of Force Emissions and Precision Mass Displacement as a Direct Function of Locus and Form of Mechanical Restraint Provided Modified "Mass Discrimination" Profiles Absence of "Weight" and "Frictional Resistance" of Objects based on Gravitational Compression Will Alter the Content and Utility of Some Afferent Kinesthetic, Proprioceptive and Vestibular Stimuli Both During Static and Dynamic States Inability to Handle Liquids, Powders and Other Loose Bulk Material Outside of Closed Containers Modified Reaction Time Due to Possible Afferent Changes and Muscle Stimulation Thresholds Requirement to Provide Forced Mixing During Heating or Cooling of Liquid or Gaseous Materials Requirement to Provide "Up - Down" Organization in Display System Based on Visual Configuration	Difficulty in Performing Unpracticed Gross Motor Movements Requiring Complex Motor Coordination in Respect to Force Emission or Displacement of Self, Free Masses or Support Instrumentation During Early Part of Orbital Residence Inability to Maintain Desired Orientation or Spatial Relationship with Objects or Facilities in the Surround in the Absence of Adquate Visual Cues Modifications in the Elapsed Time Required to Accomplish Tasks in Comparison with 1-G Surround Modifications in the Amplitude and Duration of Force Emission Requirements to Accomplish Work May Cause Possible Changes In a. Muscle Strength and Endurance b. Cardiovascular Responsivity c. Respiratory Adequacy Under Load d. Basal Metabolic Rates e. Appetitive Drives (Food and Water Quantities and Schedules of Ingestion) f. Afferent Stimuli from Distal Musculature, Tendonous Insertions, Bones, Joint Capsules, Pressure Sensitive Cutaneous Sensors and the Vestibular Systems Altered Arousal Levels Due to Possible Declines in Catabolic Activities and the Correlated Metabolic Concomitants as well as Altered Nature and Absence of Circadian Stimuli The Ability to Manipulate or Control Free Objects May be Further Disrupted Due to the Fact That Normal Force Emission During Work on Free Objects is Related to Feedback Regarding the Weight of, or Frictional Resistance of, the Item. Afferent Information will Now be Provided in Terms of Addition, Instead of Sustained Force to Compensate for Weight or Gravitational Attractions, Objects will be Moved via Impulsive Accelerations and Decelerations

5-13/14

Table 5.2-3. Potential Behavioral Modifier Matrix

Possible Overt Behavioral Manifestations	Possible Overt Behavioral Manifestations (Cont)	Behavioral Parameters Selected For Measurement	Technique
Difficulty in Performing Unpracticed Gross Motor Movements Requiring Complex Motor Coordination in Respect to Force Emission or Displacement of Self, Free Masses or Support Instrumentation During Early Part of Orbital Residence Inability to Maintain Desired Orientation *or Spatial Relationship with Objects* or Facilities in the Surround in the Absence of Adquate Visual Cues Modifications in the Elapsed Time Required to Accomplish Tasks in Comparison with 1-G Surround Modifications in the Amplitude and Duration of Force Emission Requirements to Accomplish Work May Cause Possible Changes in a. Muscle Strength and Endurance b. Cardiovascular Responsivity c. Respiratory Adequacy Under Load d. Basal Metabolic Rates e. Appetitive Drives (Food and Water Quantities and Schedules of Ingestion) f. Afferent Stimuli from Distal Musculature, Tendonous Insertions, Bones, Joint Capsules, Pressure Sensitive Cutaneous Sensors and the Vestibular Systems Altered Arousal Levels Due to Possible Declines in Catabolic Activities and the Correlated Metabolic Concomitants as well as Altered Nature and Absence of Circadian Stimuli The Ability to Manipulate or Control Free Objects May be Further Disrupted Due to the Fact That Normal Force Emission During Work on Free Objects is Related to Feedback Regarding the Weight of, or Frictional Resistance of, the Item. Afferent Information will Now be Provided in Terms of Addition, Instead of Sustained Force to Compensate for Weight or Gravitational Attractions, Objects will be Moved via Impulsive *Accelerations and Decelerations*	Requirement to Develop Technique to Replace Those Normally Utilizing Gravitational Influencing a. Pouring Liquids or Powders b. Heating Liquids in a Container (No Convection Currents for Mixing) c. Measuring Loose Materials in an Oversized Container d. Developing Procedures for Aligning and Stabilizing Soft Flexible Support Gear in Safe and Functional Arrays Crew Members Will be Able to Move "Through" a Three-Dimensional *Volume* in a 3-D Straight Line Approach Rather Than Along a Single Two-Dimensional Plane. This Capability May or May Not Require Specific Inclusion of Mobility Aids Crew Members May be Subjected to "Temperature Discomfort" if Forced Draft Dead Spaces are Present. This Could Impair Arousal and/or General Performance Perceptual Illusions May be Generated via Dynamic Stimuli Developed by Inadvertant Vehicle Dynamics Following Extended Weightlessness The Disabling Form of Space or Motion Sickness *Reported by the Russian Cosmonauts* May be Developed	(1) Arousal Levels (Level and Periodicity) (2) *Crews Psychomotor Adaptation to gG:* a. Total Body Control/Coordination (Translation or Personal Transport) b. Upper Extremity Coordination c. Precision Fine Displacement and/or Force Emission Control d. Absolute Levels of Muscle Strength and Endurance e. General Capability to Maneuver and Work in Weightless Surround (3) Modification in "Task Time Requirements" (4) Gross Assessment of Modifications in Circadian Cycles (5) Mass Discrimination (6) Capability to Maneuver and Manipulate Objects of Varying Mass, Volume and Configuration (7) Crew's Biomedical Adaptation to Weightless Environment (8) Crew's Emotional Adjustment to Weightless Environment (9) Presence of Zero-G Based Visual or Dynamic Illusions (10) Stability and Sensitivity of Vestibular Mechanism Function (11) Stability and Sensitivity of Proprioceptive and Kinesthetic Functions (12) Presence of Disruptive Space or Motion Sickness	Remote Performance Monitor (11, 12) a. TV Observation Physiologic Measures (1, 8, 10, 12) a. Heart Rate b. Blood Pressure c. Body Temperature d. Respiratory Rate and Volume e. Metabolic Rates f. EEG Post-Flight Reportorial Analysis (5, 9, 12) a. Verbal Debriefing b. Personal Diary c. Activities Log d. Formal Questionnaire Vigilance Analysis (7, 8) a. Formal Vigilance Test Device and Program (Visual and Audio Monitoring) b. Monitor and Readout of Formal Operations Tasks 1. TV Monitor 2. Operations Control Outputs Sensed and Stored for Telemetry Outputs and Ground *Analysis (If Feasible)* c. Blink Rate Monitor Utilization of the GE 3-Demensional Displacement (3, 10, 11, 12) Analyses in Order to Provide Time, Rate and 3-Dimensional Movement Analyses for: a. Accuracy to Reach 3-Dimensional Coordinate b. Effectiveness in Terms of Least Deviation from Straight Line Path c. Error Evaluation (Over or Under Shoot, Etc.) d. Elapsed Time e. Capability to Maintain a Static Position in Space (Tremor Analysis) Hand Dynamometry and/or EMG (for Tonus Measures) (1, 2, 4, 5, 6, 7) Ergometry (Bicycle) (2, 3, 7, 11) A Series of Constant Volume Stimuli (Spheres) (2, 3, 4, 5, 6, 9, 11) of Varying and Unknown Masses will be Compared - and Data will be Stored for Recovery *TV or Photogrametric Monitoring During the Handling* of Known Free Masses and Volumes. Analysis of Relative Effectiveness, Error-Free Performance and Work Envelopes will be Gained. Detailed Analysis for General Eye/Hand Dexterity will be Developed in Monitoring Selected Operational Tasks and Comparing Performances with 1-G Baselines. Direct Real Time Evaluation via Visual and/or TV Monitor Otolith Test Program (See Neurological) (2, 7, 9, 10, 12) Visual Test Procedures Utilizing a Modified Orthorater Stimulus Display (1, 4, 6, 7, 9, 12) a. Measures of Absolute Visual Acuity (2 Point Separability and Minimal Detectable Stimulus) b. Measures of Absolute Brightness Sensitivity c. Measures of Dark Adaptation Profiles d. Measures of Phorias e. Measures of Color Sensitivity f. Measures of Threshold for the Detection of Movement g. Measurements of Eye Movement (See Otolith Test in *Neurological*) Reaction Time Measurement (Simple and Complex (1, 2, 3, 4, 7, 11) for Visual and Auditory Stimulus or, if Available, a Reaction Time Test Based on Real Mission Related Operations Two-Dimensional Visual Pursuit or Compensatory (1, 2, 3, 4, 7, 11) Tracking Display. Subject will be Required to Perform Under Time Stress. On-Target Time and Other Error Scores will be Evolved. Complex Arithmatic or Memory Task Probably Coupled (1, 3, 4, 10) to Vigilance Test Programs will be Instituted to Evaluate Levels of Performance in Cognitive Areas as a Function of Time at Task as well as to Establish Levels of Function at Specific Times

Environmental Characteristics	Potential Behavioral Modifiers Assumed to be Present	Associated Latent Stressors	Potential Behavioral Implications	Possible Co
Continuous Operations (24 HR/7 Day)	Altered Circadian Rhythms Continuous Forced Social Interaction Monotony/Boredom Interference with Off-Duty Personnel in Respect to Privacy, Rest, and Recreation Limited Release or Recreational Potentials Survival Dependency Based on Continuous Optimal Performance Both Physical and Cognitive	Changes in Chronological Coordination of Arousal Level Present and Arousal Level Required for Task Completion During Pre-Adaptation Phases of Mission Personality Conflict Between Individuals Due to Forced Interactions Mission Oriented Activation may be Altered due to Lack of Immediate Results of Boredom Mission Oriented Behavior may be Altered Due to Cumulative Fatigue Cumulative Stressor Effects Without Adequate Release Mechanisms Increase Irritability and Inter-Personal Conflict as Well as Mission Oriented Activation Increased Manifest Anxiety Due to Recognition of Own Activational Difficulties or Noticing Similar Tendencies in Others	Changes in Inter-Group Behavior Changes in Mission-Related Activation Levels Changes in Manifest Anxiety Changes in Arousal Level Chronology Changes in Group Cohesiveness Changes in Fatigue Levels Changes in Emotional/Personality Adjustments	Human Per May Suffer Between Cit and Around Deteriorati Deteriorati Performanc Deteriorati Quantitativ Mission Or Physical an Developed a of Stress wi Increase in Secondary I Status Deteriorati Failure to C Responsibil Modificatio Redirection Related Ob Transient A

5-15/16

Table 5.2-4. Potential Behavioral Modifier Matrix

al Implications	Possible Overt Behavioral Manifestations	Behavioral Parameters Selected for Measurement	Techniques
roup Behavior n-Related st Anxiety Level Chronology hesiveness Levels al/Personality	Human Performance During Early Flight May Suffer Due to Lack of Coordination Between Circadian Elicited Arousal Levels and Around-the-Clock Arousal Requirements Deterioration of Inter-Personal Behavior Deterioration of Group Productivity and Performance Quality Deterioration in Individual Qualitative and Quantitative Performance Due to Lack of Mission Oriented Activation Physical and/or Emotional Failure could be Developed as a Result of Cummulative Effects of Stress with Inadequate Recovery Time Available Increase in Anxiety Levels could Trigger Secondary Disruption of Basic Physiological Status Deterioration of Command Structure with Failure to Coordinate Efforts and/or Responsibilities Modification of Irritability Thresholds Redirection of Activation to Non-Mission Related Objectives Transient Alteration in Sleep/Rest Effectiveness	(1) Group Cohesiveness (2) Motivation Levels and Direction (3) Measures of Manifest and Latent Anxiety Levels and Modes (4) Gross Assessments of Circadian Profiles (5) Individual Performance Assessment (6) Inter-Personal Relationships (Command Structure Profiles, Communication Routes and Contents, Etc.) (7) Time/Motion Analyses (8) Stability of Personality and Emotional Structure	Post-Flight Analyses of: (1, 2, 3, 4, 6, 8) a. Personal Diary b. Event Logs c. Verbal Debriefing d. Crew Inter-Communications Analysis e. Self-Administered Questionnaires Mission-Operations Based Vigilance (2, 3, 4, 5) Evaluation Both Visual and Auditory Cues Real Time Interview (1, 2, 3, 5, 6, 8) Visual and Auditory Monitoring Via TV (1, 2, 3, 4, 5, 6, 7, 8) Periodic Measurement of Anxiety Related (3, 4, 8) Physiological Correlates a. 17 Ketosteroid Excretion b. Sleep Profile c. Heart Rate d. Respiratory Rate e. Body Temperature f. Metabolism g. Sweat h. Blink Rates i. EEG j. Blood Pressure k. Body Weight l. Hand Steadiness Post-Flight Analysis or Work Quality (5, 7) or Precision of Control Outputs Recorded and Transmitted via Telemetry

Environmental Characteristics	Potential Behaviroal Modifiers Assumed to be Present	Associated Latent Stressors	Potential Behavioral Implications
High Notoriety	World-Wide Scrutiny and Judgment Great Personal Pressure to Perform in Superlative Fashion Despite Great Hazard and Unpredictability of Program Critical Analysis by Peers Knowledge of Great Stakes Involved a. National Stature b. Competition with Other Countries c. Extreme Costs Involved Potential Historic Significance Potentially Great Personal Benefits	Lack of Pre and Post-Flight Personal Privacy Living in Public Eye as U.S. Space Pilot Requires "On Stage" Behavior at all Times Potential World-Wide Exposure of all Errors or Personal Failure Total Commitment of Personal Drives to Participate and Perform Superlatively Knowledge that Nation and Program will be Evaluated on the Basis of the Crewman's Capability to Complete his Mission Successfully Knowledge that Performance Becomes Matter of Historic Record Desire to Accomplish Personal and National Political Gains Could Force High Risk Taking or No Risk Taking	Changes in Personality Structure Increase in Covert Anxiety in Respect to Capability to Perform at High Level Required Increase in Manifest Anxiety Due to Effect of Failure on Personal Status and Resultant Bad Publicity on Family Over Emphasis on Mission Could Compromise Normal Emotional Adjustments and Baseline Bio-Med Profiles Normal Behavior Could Revert to High Risk Taking to Accomplish Ends or No Risk Taking for Fear of Blame if Program Should Fail Generation of Physiological Changes Due to Increase in Sustained Anxiety Levels

5/17/18

Table 5.2-5. Potential Behavioral Modifier Matrix

Possible Overt Behavioral Manifestations	Behavioral Parameters Selected for Measurement	Technique
Increase in Anxiety Levels Disruption of Emotional Baselines Modification in Basic Personality Structure Modification in Cognitive Judgment and Decision Making Processes Over Emphasis on Operational Mission Completion at Expense of Crew Safety or Vice Versa Physiological Changes Due to High Anxiety Level Possible Challenge of Command Decision (On Board or Ground Directed)	(1) Manifest Anxiety Levels and Modes of Manifestation (2) Secondary Anxiety Related to Physiological Changes (3) Disruption or Changes in Emotional or Personality Structures (4) Changes in Decision Making Effectiveness - Time to Make Decisions - Appropriateness (5) Level and Direction of Mission-Related Activation (6) Stability of Command Structure and Individual Crew Discipline (7) Group Cohesiveness	Interviews (1,2,3,4,5,6,7) a. TV and Audio Link Pre, During and Post-Flight Post-Flight Data Evaluation (1,2,3,4,5,6,7) a. Events Log b. Personal Diary c. Self-Administered Questionnaires Real Time or Quick Time Analysis (1,2,3,4,5,6,7) of Inter-Crew and Ground Communications Measurement of Physiological Correlates (1,2,3,4,5) of Stress a. Heart Rate b. Body Temperature c. Blood Pressure d. Body Weight e. EEG f. Ketosteroid Excretion g. Respiratory Rate h. Sleep/Rest Profiles i. Blink Rate j. Hand Steadiness

Phase VIII

Phase VIII provided an extension of the work initiated in Phase VII. The specific instrumental/operational procedures for the selected measurement techniques were delineated in as much detail as possible within the time constraints imposed by the contract performance period.

Table 5.2-6 represents a summary of those areas where specific behavioral measurement procedures were shown to be indicated and Table 5.2-7 shows their distribution under the NASA behaviroal area headings. Table 5.2-8 delineates the formal instrumentation or procedural devices that have been selected to provide the data necessary and their correlation to the measurement list.

The areas delineated in Table 5.2-6 will, by cross-correlation and simultaneous analysis, provide information on all those areas of human behavior that are either sensitive to modification by the surround, or are, by their innate nature, critical to human safety.

It is important to point out that no position is taken that all the performances alterations will occur under each of the possibilities listed. Based on early flights, both Russian and American, and other data developed in formal experimental laboratories or other isolated sites on earth, there is evidence that under the specific circumstances that may be present in space the listed stressors produced performance/behavioral modification. We recognize the extremely stringent crew selection, training, and indoctrination procedures utilized will be specifically focused on eliminating the occurrance of many of the parameters listed. IMBLMS must, nonetheless, provide the capability to monitor and measure their potential presence if for no other reason than to verify the effectiveness of the selection and training program utilized.

As a result, the General Electric Company recommends providing measurements capabilities for the behavioral areas listed (see Table 5.2-6 utilizing the techniques and instrumentation suggested (Table 5.2-7).

Table 5.2-6. Behavioral Parameters Selected for Measurement:

(1) Arousal Levels (Level and Periodicity)

(2) Psychomotor Function:
Fine and Gross Motor Activity

(3) Chronological and Amplitude Shifts in Circadian Cycles

(4) Crew's Adaptation to the Physical Uniqueness of the Weightless Environment

(5) Personality Stability

(6) Emotional Adjustment

(7) Stability and Sensitivity of Vestibular Mechanism Function

(8) Stability and Sensitivity of Proprioceptive and Kinesthetic Functions

(9) Anxiety Levels and Modes of Manifestation

(10) Inter-Personal Relationships (Group Cohesiveness i.e., Command Structure, Communication Routes or Modes, Work Effectiveness, etc.)

(11) Short and Long Term Memory

(12) Absolute Measures of Selected Sensory Functions

(13) Cognitive Function

(14) Time/Motion Analyses

(15) Mission-Directed Activation

Table 5.2-7. Distribution of Selected Measures Under NASA Directed Areas of Measurement

Sensory Test Battery

Visual (12)

Auditory (12)

Cutaneous (12)

Kinesthetic (8, 12)

Clinical Evaluation

Crew Intercommunication (1, 3, 5, 6, 9, 10, 13, 15)

Learned Behavior

Reaction Time (2, 3, 4, 6, 9, 12, 14, 15)

Tracking (2, 12, 13, 15)

Vigilance (1, 3, 6, 9, 11, 12, 13, 14, 15)

Time and Motion Study (2, 3, 4, 7, 8, 13, 14, 15)

Memory, Long, and Short (1, 3, 6, 9, 11, 13, 15)

Higher Thought Process (1, 3, 5, 6, 9, 11, 13, 14, 15)

NOTE:

Numbers appearing after technique refer to corresponding number on Table 5.2-3.

Table 5.2-8. Measurement Techniques Selected for Obtaining Behavioral Data

Test Technique	Area With Prime Responsibility For Providing Instrumentation	Measurement Area Where Data May Be Applied (See Table 5.2-6)
Mass discrimination Test Kit	Behavioral	1, 2, 4, 8, 12,
Real time interview (voice)	GFE	1, 3, 4, 5, 6, 9, 10, 11, 14,
TV Visual Monitor (recommended)		1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 14, 18
On board communication recorder	Behavioral	1, 3, 5, 6, 9, 10, 14
Visual Test Equipment	Behavioral	2, 12
Reaction Time measuring device	Behavioral	1, 2, 3, 4, 5, 12, 14
Tracking Task	Behavioral plus others (common use of CRT and computer software.)	1, 3, 4, 7, 8, 12, 13
Post Flight debriefing	Behavioral plus others	1, 3, 4, 5, 6, 9, 10, 11, 14
Daily individual diary	Behavioral	1, 3, 4, 5, 6, 9, 10, 12
Periodic on-board behavioral questionaire	Behavioral	1, 3, 5, 9, 10, 11, 13, 15
Vigilance test device	Behavioral	1, 2, 12
Blink rate monitor	Behavioral	1, 3, 12
3/D displacement device	Behavioral	2, 4, 7, 8, 12, 14, 13
Vehicle activity or event log	Mission operations	1, 3, 9, 16
Photogrametric analysis cameras	Behavioral	2, 3, 4, 7, 8, 13
Short and long term memory device	Behavioral	1, 3, 11,
Audiometer	Behavioral	12
Cognitive function Test Device	Behavioral	1, 3, 5, 6, 11
Decision making		
Problem solving		
Arithmetics		
GSR (tentative)	Behavioral	1, 3, 5, 6, 9
Otolith/vestibular mechanism test	Neurological	2, 4, 7

Note

Numbers appearing after technique refer to corresponding numbers on Table 5.2-6.

Table 5.2-8. Measurement Techniques Selected for Obtaining Behavioral Data (Cont)

Test Technique	Area With Prime Responsibility For Providing Instrumentation	Measurement Area Where Data May Be Applied (See Table 5.2-6)
Keto-steriod analysis	Biochemical	1, 3, 5, 9
Eosinophile counts	Biochemical	1, 3, 9
Sweat	Biochemical/medical	1, 3, 9
Body weight	Medical	4
EMG	Medical	1, 2, 3, 4, 6, 8
Heart Rate	Medical	1, 3, 4, 5, 9
Blood Pressure	Medical	1, 3, 4, 5, 6, 9
Body Temperature (core)	Medical	1, 3, 4, 5, 6, 9
Respiratory Rate/Volume	Medical	1, 3, 4, 5, 6, 9
Metabolic Profiles	Medical	1, 3, 4, 5, 6, 9
EEC	Neurological	1, 3, 6, 9
Muscle strength	Muscolo Skeletal	2, 4
Muscle endurance	Muscolo skeletal	2, 3, 4

5.3 MEASUREMENT/TECHNIQUE SELECTION AND RATIONALE

This section lists and describes the measurements selected as providing the most pertinent material on evaluating astronaut behavior in order to generate meaningful and applicable data to protect or improve mission function and crew safety.

It will be noted that each of the measures is accompanied by a series of measurement techniques rather than a single specific measure. This is based on two premises.

a. No single measure of any single parameter is adequate to describe "behavior" or to equate the measure taken of the "total" organism under measurement.

b. Since varying mission profiles are potentially available with a series of different volumes, facilities, configurations, durations, and objectives, it is essential that differing combinations of measurement techniques be available to provide the greatest applicational flexibility with the greatest quantitative and qualitative data return.

5.3.1 MEASURE

Arousal (level and periodicity)

Definition

The activation level of the organism both on a psychological and physiological basis.

Rationale For Inclusion

Measures of arousal are justified from several points of view:

a. Altered work/rest cycles may require high levels of arousal at periods when, due to fatigue or mismatch with circadian rhythms, maximal arousal may not be "naturally" maximal.

b. During the early phases of orbital residence there may be come motility in the relatively stable earth-oriented chronology of the circadian drives, with disruption in nutritional, excretory and sleep efficiency.

c. Those parameters of influences inherent in the earth surface environment which may fluctuate as a function of a 24 hour day/night cycle may be absent in the space cabin environment and result in further disruption of circadian relationship.

d. There is ample evidence in the "isolation/confinement literature" to intimate that one of the concomitants of "hypodynamic," or "monotonous," environments is a general lowering of the amplitude of the arousal cycles present as long as the environment is unchanged.

e. One of the frequently quoted concomitants of extended "anxiety" is alteration of the subjects arousal profile. The degree and direction of the arousal change is usually considered to be a function of the individuals basic personality structure and the mode, intensity, and duration of stressors in affect.

f. Many of the detailed procedures normal to nominal "space flight" or "experimental measurement procedures" require relatively high levels of psychomotor and cognitive function both of which are directly coupled to arousal status.

g. Inappropriate arousal levels and/or rhythms on the part of astronaut crews could lead to increased irritability in respect to inter-personnel relationships. Difficulty in getting to sleep during assigned sleep periods can be erroneously blamed on lack of consideration (noise generation, lighting levels, etc.) on the part of fellow crewmen.

Utility Of Derived Data

With the establishment of data describing modifications in the time course and/or amplitude profiles of arousal, deliberate programing criteria may be developed to eliminate or minimize potentially deleterious mismatch phenomena.

In the event that direct relationships may be established for failures in arousal synchronization or amplitudes in respect to the development of emotional or general cognitive aberration, procedures may be developed to prevent the generation of such arousal discrepencies. These may include artificial suppression or activation of arousal, preflight adaptation training, modified programing, or potential automation of system sensitive functions.

Measurement Techniques Available

Real time oral interview

Blink rates

Reaction time (disjunctive)

CFF (if available)

EEG

Vigilance test device

Personal diary

Formal behavioral questionaire

Sleep profile measures

Memory test device

Cognitive test device (problem solving - arithmetics)

EMG

Metabolism

Crew intercommunication analysis

The any or all of the preceding measures may be implemented in the specific measurement of arousal providing that they are scheduled and coordinated properly. It is assumed that one or perhaps two of the measures will be so utilized. It is pertinent to note that many of the measures will be taken with other primary purposes in mind and as a result a great deal of "no additional cost" data may be derived providing adequate documentation is obtained at the time.

5.3.2 MEASURE

Psychomotor function

Definition

The subject's capability to deliberately control and utilize his voluntary musculature based on informational feedback derived from visual, tactile, proprioceptive or kinesthetic cues.

Voluntary control shall be measured in respect to:

a. Precision force emission

b. Precision displacement (rates and locus.)

c. Complex coordination as a function of timing and control of multiple spatial relationships of the body or extremeties to internal or external dynamic or static referents.

Rationale For Inclusion

There is reason to believe that in the prolonged absence of a gravitational vector some form of adaptation will occur in the musculature of the resident crewmen. At the same,time due to the absence of "weight" as a characteristic of the environment, a shift in the form and intensity of proprioceptive, kinesthetic, and tactile cues to movement will be manifested. These changes (change in muscle contractility and altered feed back during movement or manipulation of masses) could result in modifications in basic motor function.

While both these possibilities are admittedly potentially transient, if appropriate and adequate countermeasures are developed and utilized, measures of emperical performance would still be necessary to establish the fact that the programs utilized are effective.

In the event that selected corrective and/or preventive procedures are ineffectual measures in this area, the time course and mode of manifestation of such changes could be delineated.

Utility of Derived Data

These data could be utilized in real time to correct techniques or modify dosage in counter measure programs.

If the modes of manifestation and the time course of any motor deterioration are available, deliberate programing may be evolved to insure the fact that residual capabilities can match task requirements. Furthermore, if long term countermeasures to maintain earth baselines are not possible or feasible, these data could be utilized to establish minimal operational criteria in the design of the M/M interface for long term space flight. Once again if the preferred mode of handling the modified response is to permit reconditioning to occur and be maintained until just prior to re-entry, then the capability to evaluate general motor function can provide the criteria necessary to determine fitness to survive and perform during re-entry.

Measurement Techniques Available

Constant volume mass discrimination kit

Reaction time test

Eye hand tracking task

GE 3-D displacement device

Photogrametric analysis

EMG

While any one or all of the preceding could be utilized to provide data in the psychomotor area: the specific measurement selected would be derived as a function of:

a. The volumetric mass, cooling or power constraint imposed by the specific mission flight package involved.

b. Whether or not a specific measurement technique could be utilized to provide a supportive or prime function for another measurement group.

c. The crewman hour availability

d. The unique character of the experimental question involved.

5.3.3 MEASURE

Chronological and amplitude shifts in circadian cycles

Definition

Circadian rhythms represent cyclic modifications in activation levels or values in a series of physiological and neurological functions. These states or values shift in amplitude on a 24 to 27 hour period. The shifts in functional levels are assumed to be linked to various physical phenomena generated as a result of the daily rotation of the earth (day/night cycle) or to be iniated as the result of a "biological clock" and are further assumed to be responsible for the optimal activation of the organism in respect to its adaptation to survival and function.

Rationale for Inclusion

The arousal phase of circadian rhythms has been discussed under its own heading and will be excluded from this discussion.

The normal sequence and chronological distribution of such physiological activities as metabolism, body temperature, eosinophile counts etc. actually establish the total activation level of the organism. This activation (as separate from arousal) is responsible not only for the nutritional status of the musculative and nervous systems but also by the resulting metabolic shift is capable of modifying both neural activation thresholds and muscle tonus on a secondary effect basis. These responses not only control the functional potential of psycho-motor performance of the individual but also establish the baseline catabolic functions which inturn could cause modification in the basic drives activated and their levels of urgency (hunger, thirst, sex, etc.) This broad, across-the-board potential influence of circadian activation should be considered. It should be pointed out that there is evidence available to demonstrate that while an organism can readily modify his autonomic triggering mechanisms voluntarily to increase activation, it is considerably more difficult for him voluntarily to quiet or deactivate his system if it is inappropriately activated.

Utility of Derived Data

While many experimentors have looked at shifts in circadian rhythms in association with social and physical isolation as far removed from surface phenomena as possible, no extended evaluation of humans has been accomplished outside the atmosphere in a weightless state where passage through the earth's fluctuating magnetic field (due to darkside streaming) on a 90 minute has been accomplished.

Measures establishing any environmentally unique shift as well as data linking such shifting to behavioral manifestations would be of critical import to the appropriate utilization of man in space as well as setting operational and hardware design criteria.

Measurement Techniques Available in IMBLMS

Real time voice interview

On board communication recorder

Reaction time measuring device

Tracking tasks

Post flight debriefing

Daily individual diary

On board behavioral questionaire

Vigilence test device

Blink rate monitor

Vehicle activity or event log

Photogrametry

Cognitive function

Ketosteriod analysis

Eosinophil counts

Sweat

EMG

Heart rates

Blood pressure

Body temperature

Respiratory rate/volume

Metabolic profiles

EEG

Muscle endurance

Measures in this area will require careful scheduling consideration in order to sample the profiles at appropriate time intervals. In addition multiple testing to establish the physiological modifications correlates to behavioral changes would be of major value.

5.3.4 MEASURE

Crew adaptation to the physical uniqueness of the weightless environment.

Definition

Several common physical principles are modified as a function of weightlessness that exert a primary effect on the crewman's general behavioral profile, (see Figure 5.2-1). Basically the need to accelerate and decelerate objects during manipulation, the requirement for artificial restraint to emit sustained forces, the absence of gravity-generated friction, the absence of parabolic flight paths for free floating masses, the absence of a gravitationally based "up-down" referent, free soaring as a translational mode, absence of gravitational alignment of the otolith etc. The ability of the crewman to adapt to these and other parameters of the environment are considered.

Rationale for Inclusion

Major changes in general psychomotor patterns and modes of behavior will be required in order to reach maximum effectiveness in space. The speed and effectiveness with which these new procedures are adapted as natural behavior will in a large part dictate the performance effectiveness of the crewman. In some instances, failure to adapt to the modified or absent inputs to the vestibular system, in particular, have resulted in disruptive and even incapacitating motion sickness.

As a result the capability to measure and identify behavioral concomitants of the subjects mode of adaptation to zero G will be of major behavioral significance.

Utility of Derived Data

Information derived can be utilized to assess vestibular desensitization programs or drug therapies in the event that motion sickness is evidenced.

The time course of psychomotor adaptation to zero G may influence operational scheduling and even task definition.

Training profiles for preflight indoctrination may be evaluated or specific content added as needed. The design and location of restraint devices, orientation cues, free masses and even open work volumes may be based on design criteria developed by such measures.

Measurement techniques available

Mass discrimination test kit

Real time interviews

Reaction time measuring device.

Tracking task

Post flight debriefing

Daily individual diary

3/D displacement device

Photogrametry

Otolith/vestibular test

Body weight

EMG

Heart Rate

Blood pressure

Body temperature

Respiratory rate

Metabolic profiles

Muscle strength

Muscle endurance.

5.3.5 MEASURE

Personality Stability

Definition

Each crewmember will have had an extensive baseline evaluation of his personality profiles prior to selection and reasonably close monitoring during the preflight programs. It is assumed that a series of desirable traits, capabilities and drives, general defense mechanisms, and egocentric motives will have been noted and measured.

Rationale for Inclusion

The use of personality inventories in test-retest situations have demonstrated that changes in personality profile scores are not only a measure of the inventories reliability but indicative of changes in personality.

These latter changes have been attributed to such factors as a change in home environment, work situation, subjects perception of his role in life, particular stresses active at the time of test, etc.

The factors associated with long space flights, (stress, confinement, and the like) may well affect personality characteristics.

Utility of Derived Data

It is assumed that to some extent it will be desirable to establish the stability and sustained utility of these structural characteristics over the period of the flight. Any capability to monitor their activation, direction of movement, or frequency of utilization could not only provide some insights regarding prognostic judgements of operational adequacy or survival effectiveness but will also help validate selection and/or flight readiness criteria.

Measurement techniques available

Real time interview

On Board communication recorder

Post flight debriefing

Daily individual diary

On board behavioral questionaire

Cognitive function

Sensory test

Ketosteriod analysis

Heart rate

Blood pressure

Body temperature

Respiratory rate & volume

Metabolic profiles

5.3.6 MEASURE

Emotional adjustment

Definition

For the purpose of this study emotional adjustment shall be considered to be the level and mode and appropriateness of affect demonstrated overtly by the crewman in response to those parameters of the space craft environment or mission which can be identified as stressful or disrupting.

Rationale for Inclusion

The psychological literature related to high stress and isolation and confinement experimental studies have described modification in emotional adjustment in abnormal environments. Studies or empirical reports from voluntary isolation at Arctic and Antarctic stations and involuntary isolation on life rafts or in-prisons have reported a broad spectrum of emotional changes varying from almost complete withdrawal to hyper irritability. This sort of lability could be highly disruptive to mission success and, if severe enough, could compromise crew survival.

Utility of Derived Data

Information in this area would be of value in real or near-real time. If such analysis is not feasible, post flight analysis could shed light on such things as specific etiological relationships or correlations of the manifested behavior and some specific operational, hardware or environmental influence as well as the possibility to equate rates of onsets or pinpoint precursor behavior.

Measurement techniques available

Real time interview

On board communication recorder

Post flight debriefing

Daily individual diary

Cognitive function.

Heart rate

Blood pressure

Body temperature

Respiratory rate/volume

Metabolic profiles

EEG

5.3.7 MEASURE

Stability and sensitivity of vestibular mechanism function.

Definition

The vestibular system is primarily responsible for the detection of and compensatory response initiation for linear and angular accelerations of the human in respect to vector and rate of these energy inputs and, in conjunction with these phenomena, provide a sensory indication of gravitationally oriented verticality.

Rationale for Inclusion

It has been amply demonstrated that under typical acceleration modes or combinations of rate and vector histories the vestibular responses lead to illusionary perceptions of a visual or introspectively sensed nature which were capable of causing inappropriate interpretive control or compensatory responses on the part of the exposed individual.

In some instances reported during the early U.S.-USSR flights, illusionary introspective sensations of tumbling or motion sickness have been reported.

Utility of Derived Data

Quantitative measures of such phenomena when correlated to the dynamic history experienced could lead to greater definition of causality as well as a possibility to equate the dynamics involved with sensation severity. In addition, such techniques could be used to evaluate the effectiveness of preflight desensitization programs or drug therapies.

Measurement technique available

Tracking task (adaptive program)

3-D displacement device

Photogrametry

Otolith/vestibular test

5.3.8 MEASURE

Stability and sensitivity of proprioceptive and kinesthetic functions.

Definition

The functional integrity and threshold sensitivities of those sensory mechanisms (both afferent and efferent) related to the perception and compensetory activities are important for the maintenance of both the static and dynamic physical relationships of the various segments of the body in respect to one another or an external referent. Information regarding relative 3/D locus, some aspects of force generation/emission and some aspects of reciprical or coordinative dynamic movement are included.

Rationale for Inclusion

Kinesthetic and Proprioceptive inputs in an earth surface environment are usually based upon data derived from the activation of musculo-skeletal stretch mechanisms during their function against or along a gravitational vector. While voluntary motor activity in zero G will still create a level of activation of stretch receptors; in the absence of gravity the amplitudes and durations of the outputs of the stretch receptors will most certainly be modified due to the shift from "weight" reactions to "inertial" reactions.

While no major perturbations have been noted during operations wherein the crewmen were firmly stabilized in couches, some operational awkwardness was experienced during both US and USSR EVA operations. Whether or not some proprioceptive and/or kinesthetic disruption was involved is yet to be determined.

Utility of Derived Data

Should some alterations of functional integrity or sensitivity threshold, or the capability to interpret and utilize such information be detected, the implication to performance during re-entry or recovery operations could be a major impact. In addition, should such modifications be identified, a countermeasure program directed at eliminating or minimizing the adaptation could be initiated.

Finally, should there be some period of transient capability before the crewman was fully adjusted, operational hardware could be capable of being designed to minimize the consequences.

Measurement techniques available

Mass discrimination test kit.

Reaction time measuring device

3/D displacement device

Photogrametry

EMG (reciprocal muscle measures)

5.3.9 MEASURE

Anxiety levels and modes of manifestation

Definition

For the purposes of this program anxiety shall be considered to be those responses related to or caused by the individual's "concern for" or "apprehension regarding" or a series of real or possible events that would cause injury to or thwart the desires of the individual involved.

"Anxiety" in this definition is simultaneously a result of inputs from the physical, operational and emotional environment and is the cause of both psychological and physiological modifications. These primary systemic modifications may then cause further modifications in the modes and amplitudes of the subjects response on a secondary basis.

Rationale for Inclusion

The active development of high levels of anxiety could cause serious disruptions in the crewmember's ability to perform in psychophysical, cognitive, or psychophysiological areas.

Utility of Derived Data

Deliberate measurement of alterations in anxiety profiles could possibly lead to the identity and quantification of causal factors, which once identified could possibly be reduced, or eliminated, through crew selection.

Measurement techniques available

Real time interview

On board communication recorder

Post flight debriefing

Daily individual diary.

Periodic on board behavioral questionaire

Vehicle activity or event log

Ketosteriod analysis

Eosinophil counts

Sweat

Heart rate

Blood pressure

Body temperature

Respiratory rate & volume

Metabolic profiles

5.3.10 MEASURE

Inter-personal relationships

Definition

For the purposes of this program inter-personal relationships refer to both individual and group functions requiring cross communication or cooperative actions on a direct or indirect contact basis between the members of the flight crew, or between flight crew members as individuals or a cohesive group and individual ground communicators, interviewers, authorities or the ground complex as a whole.

Rationale for Inclusion

The requirements for the crew to cope with large quantities of highly accurate cognitive and functional outputs on a continuing basis will require a large degree of high level cooperation between all individuals and groups concerned. Any mechanism acting to deteriorate desirable inter-communication routes would constitute a severe disruptive influence to all aspects of mission success. While extensive work has been done in small group interaction and communication pathways for optimal effectiveness of organization, little substantial research has been done for highly isolated, forced interaction groups.

Utility of Derived Data

The description and analysis of crew interaction profiles could help establish not only possible modes and manifestations of any disruptions or possibly improvements to the basic operational interactions and subsequent productivity effectiveness, but could perhaps help identify the factors creating the modifications. If such identifications can be affected, valuable insights to subsequent operational program design, task organization and scheduling, crewman hour programming and the desirability of specific crew personality characteristics for selection criteria may be gained.

Measurement techniques available

Real time interview

On board communication recorder

Post flight briefing

Daily individual diary

Periodic behavioral questionaire

5.3.11 MEASURE

Short and Long Term memory

Definition

For the purposes of this report short term memory will refer to the retention of either visual or auditory alpha/numeric or non-verbal material for a period not to exceed 3 minutes from the time of presentation until test. Long-term memory evaluation shall be considered to exceed 24 hours (stimulus presentation to test).

Rationale for Inclusion

Memory has long been utilized as a measure of attention span, personal activation and general cognitive functions or learning abilities. Within certain limits a given subject can perform quite uniformly when tested as a function of similar non-associative material. This is not say that an individual's capability to retain specific loads of material of specific complexity as a function of time can be fairly standardized, especially for short term periods. As the periods lengthen there is evidence tc demonstrate that this long term memory also holds fairly constant except for the fact that "what happens during that time" (retroactive inhibition) is just as critical as elapsed time between learning and recall.

Utility of Derived Data

In this area as in others the greatest value in the measures taken lies not so much in the absolute measures developed as much as it it in the deviation from known baseline.

Memory spans provide insights not only in learning ability and personal commitment, but could conceivable provide supportive material to establish overt personal subjective evaluations of stressors that occur between the presentation and recall.

Measurement techniques available

Real time interview

Post flight debriefing

Periodic behavioral questionaires

Cognitive function tests

5.3.12 MEASURE

Absolute measures of selected sensory functions.

Definition

For the purposes of this program measures will be evolved for vision, audition, cutaneous and labrynthine functions (labrynthine functions are discussed separately under vestibular function).

Rationale for Inclusion:

The extreme criticality of sensory functions for crew performance and survival is self evident. Measures in this area would be justified if for no other reason than to establish the fact that no deterioration has evolved as a function of residence time. However, while no overt manifestations have as yet been noted during any US-USSR Space flight programs, certain systemic hematological and cardiovascular changes have been noted. There is feeling in many quarters that if vascular and hematological modifications become excessively altered, a secondary manifestation, altering sensory function could be evolved. There is also some opinion, although not evidenced emperically, that the absence of a gravitational vector could disrupt the extra-occular musculature coordination as well as the concept that eye ball configuration could be modified in the absence of gravitational compression.

Utility of Derived Data

The specific measures selected for testing are covered in the Measurement Specification Sheets (Appendix A) as well as in the addendum of additional measurement recommendations.

The primary utility of these measures is inherent in the fact that the crewman's function in the system is completely based on his capability to sense and respond to his environment. Until we can be absolutely sure that his sensorium will not be degraded by his residence in orbit, we must be capable of monitoring these function capabilities.

Measurement techniques available

Real time interview

Reaction time measuring device

Visual test equipment

3/D displacement

5.3.13 MEASURE

Cognitive function

Definition

For the purposes of this program, cognitive function is assumed to be synonymous with higher thought processes with the exclusion of memory which was treated separately. Its primary concern is the measurement of the individual's capability to carry on effectively in respect to decision making, problem solving, computational capability and the ability to apply his intellectual/technological skills effectively.

Rationale for Inclusion

There is reason to believe that some modification in general cognitive function may develop as a function of such influences as sustained anxiety, increased irritability, isolation, confinement, sustained operations, monotony, and altered circadian rhythms. At the present time the severity or time course of such potential modification is undefined.

Utility of Derived Data

Measurement in this area will not only provide data for the above but could also provide the basis for mission abort should some unforseen and/or undetectable toxicant of ECS system failure degrade cognitive function.

Cognitive measures should also be considered in respect to possible misalignment with task requirements by inadequate arousal due to circadian shifting or programming inadequacies.

Measurement techniques available

Mass descrimmination test kit (decision time)

Real time interview

On board communications recorder

Reaction time measuring device (disjunctive)

Post flight debriefing

Daily individual diary

Periodic on board questionaire

Short and Long term memory

Cognitive function test device.

5.3.14 MEASURE

Time motion analysis

Definition

For the purposes of this program time/motion analysis are defined as those measures designed to establish data regarding:

a. The elapsed time necessary to accomplish a complete task as well as the identification of time consumption requirements for each reasonably separable functional series; and

b. the motion analysis information necessary to define such pertinent data bits as work envelopes, error frequency and type, inadequate procedural or operations design, inadequate hardware or support gear design and possibly training or skill level adequacy.

Rationale for Inclusion

The principal purpose of man in the vehicle is to accomplish useful work effectively. The total man hours available in any mission flight is finite; therefore, it is expedient to insure the fact that the best possible use is made of the available man hours. This is done by adequate task, hardware, support gear and operational design as well as appropriate crew training.

Utility of Derived Data

The derived measures may be directly applied in either design or operational validation procedures, or in the establishment of basic vehicle configuration, hardware, operations, support equipment or training design programs.

Measurement techniques available

Tracking tasks

3-D displacement device

5.3.15 MEASURE

Mission directed Activation

Definition

For the purposes of this program we assume this area to relate to the level of voluntary commitment of the individual to the successful implementation of mission-related functions as expressed by the effort and time he is willing to expend in its successful completion. A further avenue of measurement is the level of precision or compulsiveness he displays or voices.

Rationale for Inclusion

The literature of isolated groups makes frequent mention of alterations in the levels and direction of mission oriented activities as a function of residence in the environment and the extend to which the mission has a personal related ego involvement.

All the problems inherent in the closed ecological system (confinement, forced social interaction, monotony, anxiety, etc.) tend to drive personal commitments and activities toward the alleviation of personal irritants or discomforts rather than toward mission goals. Some indication is present to suggest that this redirection phenomenon is not continuous in its intensity or direction over the mission course.

Spurt or "end effect" phenomena are frequently discussed but rarely documented.

Utility of Derived Data

Information generated in this area could pin-point the possible etiology of modification, in which case redesign could be considered for subsequent procedures. If time course effects prove to be stable in reference to time and mode of response, specific training or operations scheduling could be accomplished to compensate for the changes. Should all connective approaches be inadequate, measures capable of pin pointing mission directed activation levels that are inadequate could be utilized to help establish the limits of individual residence times.

Measurement techniques available

Real time interview

On board communication recorder

Reaction time measuring device

Post flight debriefing

Daily individual diary

Periodic on board questionaire

3/D displacement device.

5.4 SUGGESTED INSTRUMENTATION ALTERNATIVES

5.4.1 GENERAL

In order that the due date of the final report be met, it was necessary to establish a formal "configuration freeze date." Whenever this procedure is followed during a developmental program, it becomes necessary to exclude from the formal design many promising but inadequately defined items that would, if time permitted, merit further consideration. The following material represents three such instrumental considerations that while distinctly meritorious were at the time of the configuration freeze too poorly defined for inclusion. The use of an on-board TV monitoring system, its advantages and penalties, is discussed in Volume 3, Section 4.

5.4.2 MULTIPARAMETER VISION TEST DEVICE

Visual function has been identified as a behavioral area requiring consideration for measurement in IMBLMS. Astronaut vision, (in spite of the fact that no observable degradation has been noted in space flight operations to date) has been selected for measurement because of its extreme criticality to crew survival and mission success, as well as the fact that prolonged residences could lead to vascular changes potentially capable of disrupting retinal or other optically related circulation and cause failure in visual function as a secondary effect.

The specific visual parameters originally selected for measurement were acuity, dark adaptation, absolute brightness thresholds, color discrimination phorias and depth perception. In the course of a continuing evaluation which included extended discussion with outside consultants, an additional set of performance critical parameters meriting measurement consideration were identified.

Critical Flicker Fusion Thresholds

This measure has been evaluated extensively and has been demonstrated to be an extremely sensitive indicator of the general health and functional integrity of those portions of visual system that have to do with the detection and critical integration of light stimuli.

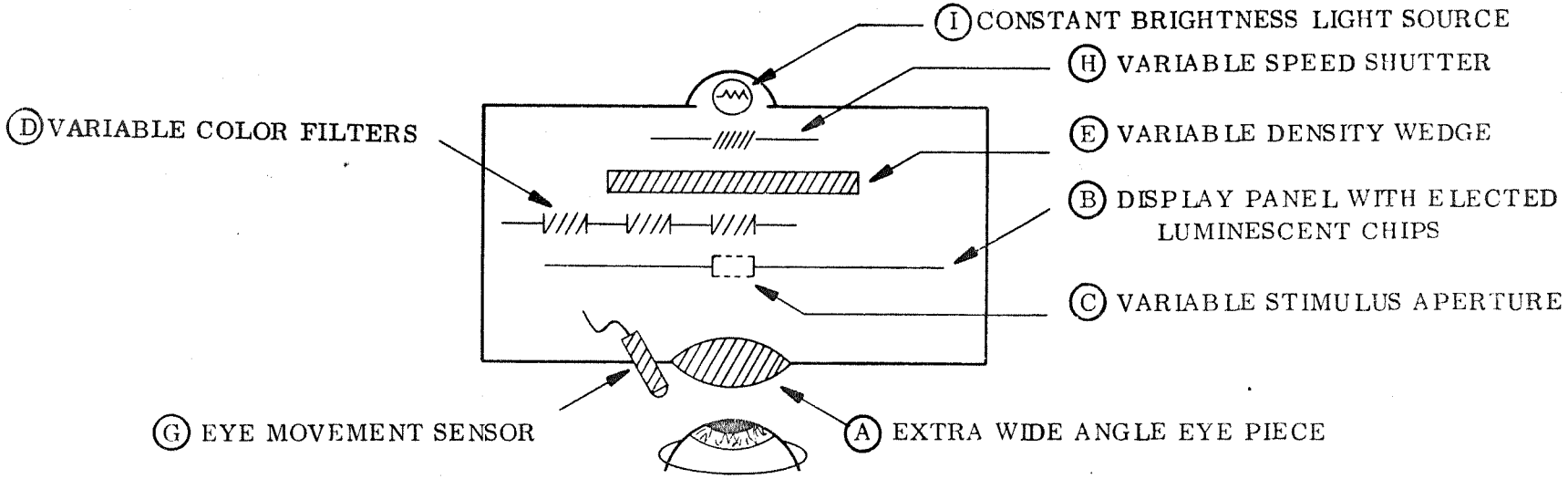
Eye Motility

Based on commentary in the literature there is reason to believe that some modification could occur in the general configuration of the eye when it is released from the compressive distortion of the eye present in 1g. In addition, a potential motor disfunction generated when the movement of the eye becomes an "inertial function" rather than a "weight displacement" function has been suggested. If these phenomena exist, (and that is yet to be determined) it is reasonable to assume that some modification in coordinated performance of the extraocular muscles might be manifested. The criticality of efficient eye motility is self-evident and as a result measurements assessing eye motility should be included. These are reaction time, traversal accuracy, and resting tremor frequencies and amplitudes.

Visual Fields

Evidence has been compiled that demonstrates modifications in the sensitivity of the visual field to stressful circumstances. Some of these, such as loss of peripheral sensitivity to light or color, have been described as results of retinal anoxia or exposure to accelerations across various body vectors. Once again the criticality of having efficient function throughout the visual field during monitoring of complex flight maneuvers justifies its inclusion as an IMB LMS measurement until the absence of alterations can be demonstrated.

With the addition of these potential measures, canvasing of potential vendors failed to disclose any single device that would be capable of providing the indicated measures. As a result the General Electric Company evolved an approach utilizing state-of-the-art measurement techniques but incorporating unique display formats and instrumentation . In order for the device to be appropriate for inclusion in a spacecraft, ground rules were developed to maximize reliability and measurement effectiveness while minimizing weight, volume, and power requirements. The device in its current state of design is shown in Figure 5.4-1.



(A) represents a monocular "extra wide angle" eye piece

(B) represents a display panel to which an array of independent electroluminescent chips have been attached

(C) represents a variable aperture stimulus port penetrating the center of the elctroluminescent panel.

(D) represents a series of color filters capable of being introduced between the stimulus port.

(E) represents a variable density wedge

(G) represents an eye movement sensor which may be incorporate in the body of the test device or utilize the EOG capability already part of the IMB LMS armamentarium.

(H) represents a variable speed shutter located between the light source and the wedge

(I) constant brightness white light source

Figure 5.4-1. Schematic for Alternate Mode Vision Tester

Figure 5.4-2 represents the basic configuration of the display format on the electro luminescent panel. Each of the dots in the circular array represents an independent electro luminescent light chip providing a visual output somewhere in the red frequency. Chips may be selectively illuminated singly, in combination, or sequentially. These fixation points when placed in the fovea serve to position the test stimulus at a precise retinal location. The circular arrays will be so positioned as to compensate for the visual distortion caused by the wide angle lens, and provide a display of equidistant concentric rings to the retina. Figure 5.4-3 represents a function flow block diagram describing the operation of the device.

The device as currently conceived could provide measures in the following areas utilizing the described procedures:

Dark Adaptation

The subject is requested to fixate on a selected red E. L. chip so located as to center the white stimulus light on the retina. The stimulus aperture is adjusted to provide an adequate image dispersion on the retina so as to insure the inclusion of both rods and cones in the sensitivity measures. The variable density wedge is positioned so as to completely occlude the passage of light. The shutter is then cycled at a constant "open phase" duration but with a varying inter-stimulus time as the wedge is deliberately withdrawn to permit controlled light transmission.

The subject reports his first perception of light by depressing an appropriate manipulanda. If the response was made during one of the random light presentations, it is considered as the threshold level for that point in time. If the crewman's response is made during an off-period, it is considered (and recorded) as an error and the sequence continues. The process is repeated for a preselected period of time (from 15 to 20 minutes per test sequence) with each value recorded and plotted for time. Stimulus presentation will be approximately 100 milliseconds in duration with from 0.5 to 2 seconds between presentations.

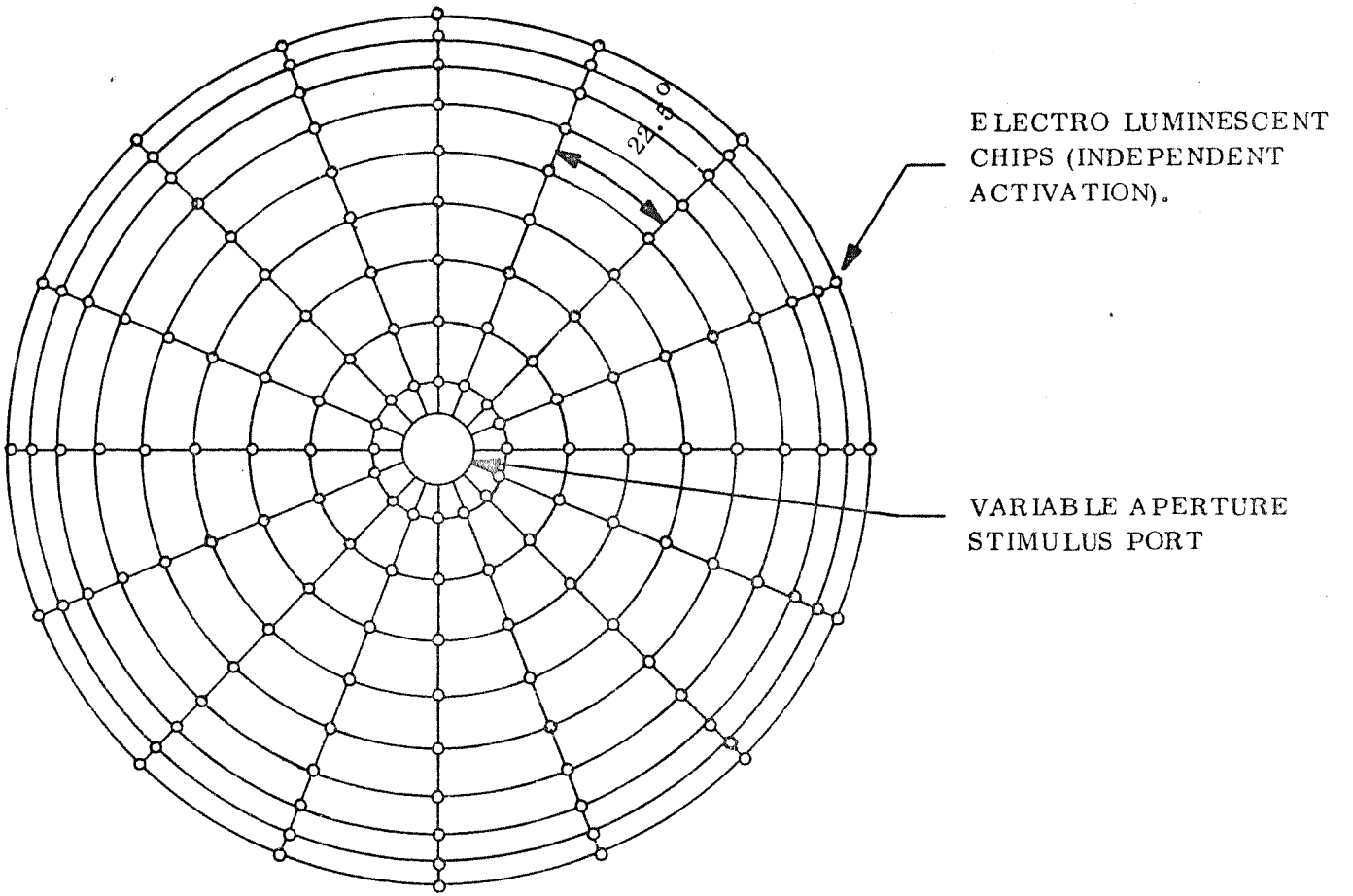


Figure 5.4-2. Display Target Points

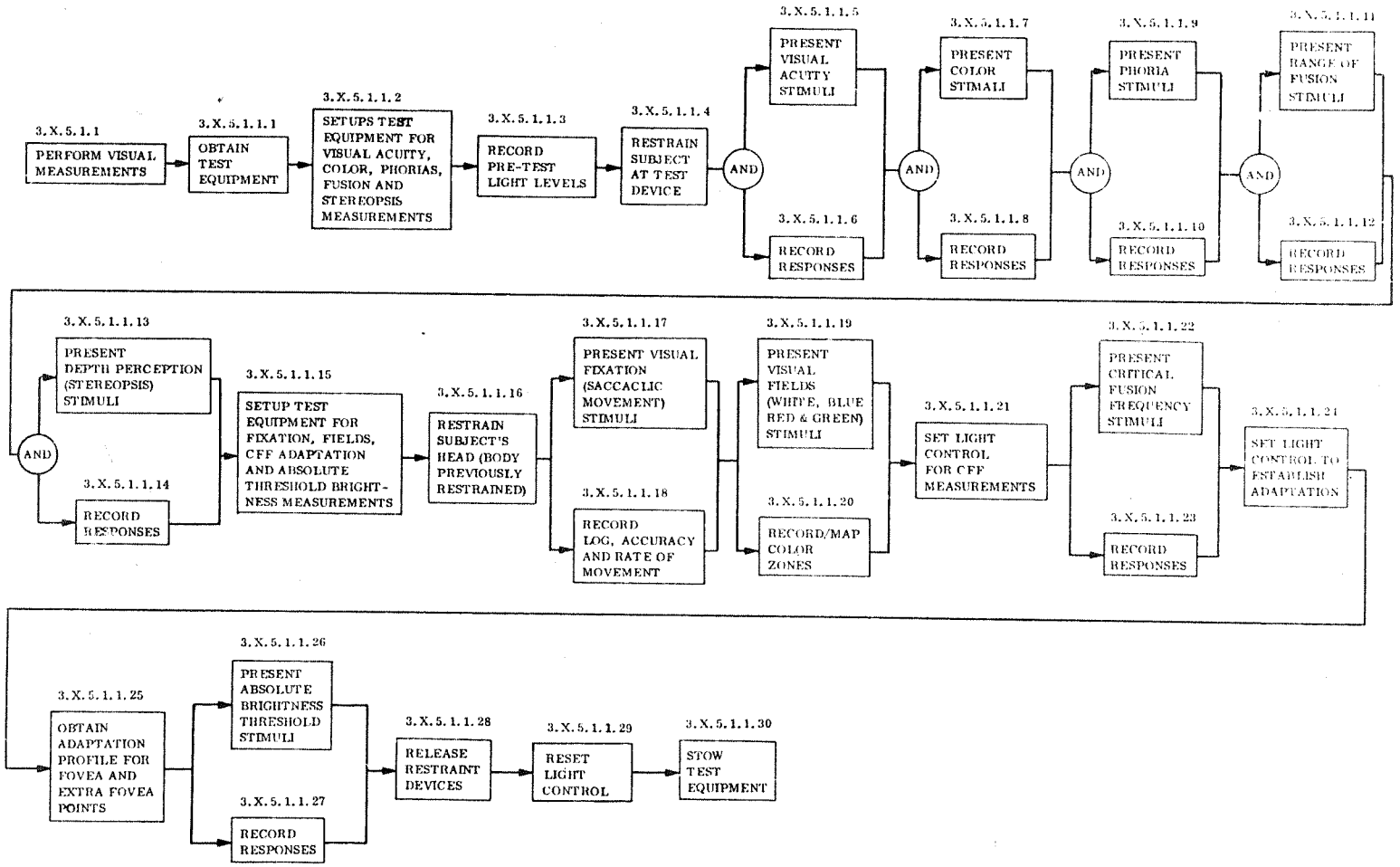


Figure 5.4-3. Perform Visual Measurements (Alternate Version)

At that point in time a preprogrammed sequence of fixation points will be illuminated in a random manner. The subject will be required to shift his vision from point to point fixating each point as it is illuminated. Measurements will be taken in analog form representing the displacement of the eye from its previous or resting position as a function of the time course of the motion history (2/D displacement/time). This will provide us with information regarding response time (eye movement latency), accuracy of movement, and fixation stability.

Visual Field Mapping

The field mapping procedure will require that the subject stabilize his head and eye with the biteboard and don the selected eye movement detector device. The variable aperture size will be diminished so as to provide an appropriately sized stimulus for field mapping. The shutter will be closed but so programmed as to provide a fixed duration stimulus with a random inter-stimulus presentation to increase successive levels of stimulus brightness. The subject will fixate on selectively activated fixation points until a stimulus becomes visible, where upon the crewman will activate a response key. At that point the crewman's manual response will not only record the locus and value of the threshold point, but would step the system to its next setting. This mapping should be done following a deliberate controlled dark adaptation level either by wearing adaptation goggles for a preset period prior to test, or by conducting the field mapping immediately after dark adaptation evaluation procedures. Should it be desirable to conduct field mapping at ambient adaptation levels, adequate intervals between test stimulus will be provided to permit readaptation to ambient light. Identical procedures could be utilized for color mapping with the exception that a selected color filter will be positioned in front of the stimulus port prior to stimulus presentation.

The remaining visual measures of acuity, depth perception, color discrimination and phorias may be measured via the static slide stimulus material presented in either an orthorator type device or a simple controlled resolution projection system with provision made for ambient light control and lead fixation to maintain control of the visual angle of the stimuli at the eye.

Absolute Brightness Threshold

Two values for this measure will be derived from the proceding dark adaptation test program. The sensitivity levels maintained at brightness threshold levels for the ambient cabin light levels will be represented by the first measure taken for the dark adaptation curve. Absolute maccular brightness threshold will be represented by the last measure taken. Following the last dark adaptation measurement, the subject will shift his eye to a new fixation point which will place the test stimulus "which has been reduced in size" to a selected location in his retinal periphery. One set of 3 measures will be taken and will represent the crewmen's absolute brightness threshold.

Critical Flicker Fusion

All fixation points will be extinguished and the stimulus aperture will be expanded to its widest opening. The wedge will be positioned to provide a specific time and constant level of illumination. The shutter will be set at a speed so as to provide a standard light/dark ratio at a rate high enough, (dependent on selected values for stimulus size, brightness, color frequency, and retinal image location) to provide an illusion of apparently steady illumination. The subject will manipulate the shutter speed so as to pinpoint that shutter speed so as to pinpoint that shutter frequency where flicker first becomes noticable. The setting (i.e. flicker frequency threshold) will be noted and the test repeated until at least 5 settings are obtained.

Both descending (fusion to flicker) and ascending (flicker to fusion) could be evaluated.

Eye Motility

The subject will position his eye at the eye piece, stabilizing his head in respect to the system by clamping on a fitted biteboard. In addition, the eye movement sensor incorporated at the eye piece will be activated and/or IMB LMS EOG will be donned. A selected fixation point will be illuminated at a selected point at the extreme end of the visual field, the subject will fixate on it and the eye movement system calibrated. This process will be repeated for at least 3 other displacements in order to provide an adequate 2 dimensional field calibration.

5.4.3 REACTION TIME MEASUREMENT

Reaction time measurements have been called out as being one of the areas of fruitful measurement in the description and quantification of the crewman's behavioral state. Unfortunately, the literature demonstrates that there is a high variability within individuals in respect to the stability of their reaction time performances. This variability always increases Type II error probability. This is to say that high performance variances can obscure or wipe out moderate or low levels of change generated by an experimental variable. While the experimental instrumentation advocated for IMBLMS utilizes an acceptable standard approach to data collection, it still suffers in sensitivity as a result of the fact that it makes no unique effort at minimizing variability beyond the implementation of approved standard techniques.

Traditionally, reaction times are taken by having the subject actuate or release a mechanical switching device following stimulus presentation. This approach increases variability as a function of the fact that pressure must be exerted to trip the device and some mechanical displacement must occur. Most such mechanical devices can be modified functionally in respect to changes in tripping pressure and travel generated with use and, in most instances, the capability to control these parameters is not included as an experimental control. The Cornell Aeronautical Laboratory** has recently advised us of a new technique that utilizes two contact plates for reaction time measurement. The CAL technique requires the subject to shift a finger from one plate to the other. The task described yields three measures:

a. Elapsed time from stimulus on-set to removal of finger contact from plate 1.

b. Elapsed time from loss of contact at plate 1 to contact at plate 2.

c. Total elapsed time to contact the second plate.

Data generated and reported to us in summary by CAL demonstrate enormous reductions in performance variability. Table 5.4-1 represents the decrease in variance expressed

** THIS DATA IS PROPRIETARY TO A CONTRACTOR NOT PRESENTLY UNDER CONTRACT, THEREFORE THE "SUBCONTRACT DATA" CLAUSE OF CONTRACT NASW1630 IS NOT APPLICABLE.

in milliseconds that was gained by shifting from the standard telegraphers key response to the plate system. The results presented were obtained in a pilot study where two subjects were utilized and given 200 trials utilizing a plate device and 200 trials with a key. The variances shown represent the spread generated during the final 20 trials for each of the test techniques (key versus plate).

While this approach did not have time for incorporation in the formal portion of the final report, its apparent increase in performance reliability would make it a much more sensitive device. As a result, serious consideration should be given its potential incorporation in the IMBLMS program.

Table 5. 4-1. Reaction Time Variances

SUBJECT	VARIANCE (m. sec.)		
	PLATE	KEY	DIFFERENCE
1	244.91	662.81	417.90
2	1780.64	2869.04	1088.40

5.4.4 EEG/SLEEP EVALUATION DEVICE

In the analysis of human behavior, measurement of general circadian profiles in respect to arousal/sleep were evolved as areas deserving major considerations in behavioral assessments.

In the profiles selected for the final report, EEG records, especially those related to the Alpha rythms, were to be compressed and telemetered to the ground for analysis. Modification of the Alpha rythms have a fairly wide-spread acceptance as representative of some quantifiable measure describing the organism's level of sleep/arousal. Cornell Aeronautical Lab,** in response to our query reported on a recently developed solid state device which they call a "Sleep Meter" capable of operating "directly on an EEG signal in the computation of the level of sleep of a human subject." The analysis approach is based on assumptions derived from the Johnson Power Spectral Functions[1] (1965) to develop a simple voltage analog of the four levels of sleep. It is proposed in this approach that the power spectral function, unique for each level, may be represented by a central frequency which is a monotonically decreasing function of the sleep level. Rice[2] (1944) demonstrated that the critical element of the Fourier transform of such a signal can be extracted by the measurement of zero-crossing rates of the signal according to the formula:

$$\bar{\dot{n}} = \sqrt{\text{NUM} - \frac{\int_{\cdot}^{\infty} F^2 \phi(F)\, dF}{\int_{\cdot}^{\infty} \phi(F)\, dF}}$$

When - $\bar{\dot{n}}$ = Average zero-crossing rate

F = Frequency

ϕ = Power Spectral Density

[1] Johnson, et al, Stability of Auto Spectra, Electro-Enceph. Clin. Neurophysiol, 1959, 19, pp. 305-308

[2] Rice, S.O., Statistical Analysis of Random Noise, Bell System Telephone Journal July, 1944.

**THIS DATA IS PROPRIETARY TO A CONTRACTOR NOT PRESENTLY UNDER CONTRACT, THEREFORE THE "SUBCONTRACT DATA" CLAUSE OF CONTRACT NASW1630 IS NOT APPLICABLE.

The CAL sleep meter, then, performs this computation giving a voltage output proportional to the depth of sleep. The group then validated the approach by analyzing a series of records on magnetic tape provided by Dr. LaVerne Johnson of the Navy Medical Neuro-Psychiatric Research Unit. Dr Johnson had conducted a standard Fourier analysis of these tapes identifying the four levels of sleep they described. The report received from the CAL Life Sciences Section stated that "when the signals from these tapes were read by the sleep meter, it was able to discriminate accurately the four levels of sleep." The advantage manifests itself in the ability to provide real time descriptive readouts of sleep profiles by an untrained astronaut, as well as providing a superior data compression technique. The current bread-board prototype device can be packaged in a 3 cu. in. volume. The impression gained during discussions with CAL was that this volume could probably be reduced by at least one order of magnitude with modest subminiaturized packaging.

It is recommended that the inclusion of this device as an IMBLMS capability should be considered in any subsequent operations.

SECTION 6

MEASUREMENT INTEGRATION

6.1 SUMMARY

An analysis of the integrated requirements of the recommended measurements, methods, and frequencies was undertaken to confirm the reasonableness of these recommendations as equipment requirements and as the basis for consumables logistics calculation. This analysis took the form of a preliminary calculation of crew time required versus that available.

Based on a 60-day biomedical/behavioral mission, the preliminary measurement time and frequency requirements are within the estimated time available:

Estimated Time Available: 1,269 hours (3 men)

Estimated Measurement Time: 896.2 hours (3 men)

The laboratory analyses are the behavioral measurement data samples returned to earth after a 60 day mission amount to approximately 118.2 pounds and occupy a volume of 3.5 cubic feet. These items which includes two freezers and a refrigerator, can be readily handled in the return CSM based on data obtained in the Cluster Mission Data Book.

Logistics examination determined that a 60-day mission requires approximately 100 pounds and 3.8 cubic feet for consumables. Resupply may be handled by a single 20 x 20 x 30 inch IMBLMS segment (including two freezers and a refrigerator to replace those returned with specimens plus 2 cubic feet available) at 115 pounds total.

6.2 PRELIMINARY CREW TIME REQUIREMENTS DETERMINATION

A preliminary calculation of crew time requirements was undertaken primarily to confirm that the recommended measurements, measurement methods, and measurement frequencies may reasonably be accomplished within crew time available. This confirmation both confirms the recommendations as equipment requirements and form the basis for examination of the logistics of consumables for IMBLMS.

6.2.1 ASSUMPTIONS

a. 60-day Biomedical Mission

b. Day 1, 2, 3 and 4 required for launch, orbit insertion, docking, and preparing cluster for mission activities. Day 59, and 60 required for securing cluster and de-orbit activities.

c. Measurements can be performed on Days 5 through 58.

d. Crew members will be allocated 8 hours per 24 for sleeping.

e. More than one crew member can be sleeping at the same time.

f. One man will always be in the CM although he may be asleep.

g. Crew members will be allocated 3 hours per 24 for meals and snacks.

h. Crew members will be allocated 2 hours per 24 for rest and relaxation.

i. Crew members will be allocated 2 hours per 24 for general housekeeping.

j. Approximately every seventh day will be allocated as non-experiment (except for certain measurements required daily) days for crew rest and operational tasks.

k. Non-experiment time per day is as follows (per man)

Sleep - 8 hours (can include CM time)

Meals - 3 hours

Rest and Relaxation - 2 hours

Housekeeping - 2 hours

l. Experiment time available per day per man is 9 hours.

m. 47 days are available for IMBLMS experiments (54 days minus 7 crew "free" days).

n. A total of 1269 hours IMBLMS experiment time is available (47 days times 9 hours x 3 crew members). (Does not include time for measurements required daily.)

o. Crew skill level is equivalent of that of a medical technician.

p. Automated data management and semi-automated calibration is included.

q. Safety monitoring is not considered.

6.2.2 METHOD OF CREW TIME CALCULATION

The following steps have been taken to reach the present measurement frequency schedule. This schedule is recognized as only preliminary.

a. Estimates were made of the recommended measurement time elements; (see Table 6.2-1).

   1. Set-up time

   2. Performance time

   3. Take down time

b. Repetition rates were developed based on the recommended measurement list. They are somewhat arbitrary first approximations and vary from 6 times daily to once per 10 days based on expected changes. No assumptions were made concerning factoring in the results of previous missions, although it is recognized that frequencies may be decreased early in the mission and increased later in the mission based on such data.

c. It was assumed that the measurement was made with the stated repetition rate on each crew man (X 3).

d. Initially the measurements were conceived as taken singularly (See Table 6.2-1.) except for biochemical sampling (blood and urine), where a single sample sufficed for multiple determinations and the time allocated corrected.

e. Relationships among measurements were next considered. It was considered that in the physiological and behavioral area no single measurement would ever be made: a minimum of two variables would always be measured together to establish some relationship. For biochemical analyses it was assumed that a single sample would be used for more than one determination. As a result the measurement frequency table was revised to reflect these measurement commonalities.

f. The next consideration was equipment commonality and automation of data management. Calibration was considered to be semiautomatic. Procedural information was assumed to be readily available by computer call-up. Sampling and recording sequences were assumed automatic in the data management system. Times were examined and corrected where required.

Table 6.2-1. Preliminary Measurement/Frequency/Performance Time Estimates for Independent Measures (Measurement Combinations for Simultaneous Measures Appears on Table 6.2-2)

Measurement	Preliminary Frequency	Preliminary Measurement Performance Time (Minutes)		
Physiological		Prepare For Measurement	Perform Measurement	Secure From Measurement
Cardiovascular				
Cardiac Output	once/man/5 days	2	5	2
Phonocardiogram	once/man/5 days	3	5	3
Alveolar to Arterial Gradient (AAG)	once/man/5 days	7	3	7
Vector Cardiogram	once/man/5 days	10	40	10
Arterial Blood Pressure	Twice/man/ day	3	5	5
Regional Blood Flow	once/man/5 days	2	3	1
Arterial Pulse Contour	once/man/5 days	5	5	5
Thoracic Blood Flow	once/man/5 days	5	5	5
Venous Compliance	once/man/5 days	10	10	5
Peripheral Venous Pressure	once/man/5 days	3	5	3
Respiratory				
Oxygen Consumption	once/man/10 days	10	5	5
Respiratory Rate	once/man/10 days	5	40	3
Lung Volumes	once/man/10 days	5	5	5
Pressure, Volume & Flow	once/man/10 days	5	5	5
Breath-by-Breath Analysis	once/man/10 days	5	5	5
Ventilation	once/man/10 days	10	15	5
Diffusion	once/man/10 days	10	15	5
Perfusion	once/man/10 days	10	15	5
Metabolism and Nutrition				
Electromyrogram	once/man/10 days	10	10	5
Energy Metabolism	once/man/10 days	10	40	10
Muscle Size and Strength	once/man/10 days	2	3	2
Body Mass	once/man/10 days	3	5	3
Core Temperature	once/man/10 days	2	40	2
Caloric Intake	Each time nutrition taken	2	3	2
Neurological				
Angular Acceleration Threshold	once/man/10 days	10	5	10
Oculogyral Illusion	once/man/10 days	10	5	10
Ocular Counter Rolling	once/man/10 days	15	5	10
Visual Task with Head Rotation	once/man/10 days	10	10	10
Agravic Perception	once/man/10 days	5	10	5
Electro-encephalogram	once/man/10 days	10	--*	10
Electro-nystagmogram	once/man/10 days	10	5	5
Behavioral				
Sensory Test Battery	once/man/10 days			
Visual		5	50	5
Auditory		5	20	5
Kinesthetic		5	40	5
Learned Activity	once/man/10 days			
Reaction Time		5	12	5
Tracking		5	10	5
Vigilance	once/man/10 days	5	110	5
Higher Thought Processes	once/man/10 days	2	20	2
Memory	once/man/10 days	2	20	2
Time and Motion	once/man/10 days	5	20	5
Clinical Evaluation	once/man/day	5	10	5
Laboratory Analysis				
Feces	once/man/day		75	
Urine	once/man/day		40	
Sweat	once/man/7 days		120	
Blood (whole, plasma Serum)	once/man/day		65	
Microbiology	once/man/7 days		180	
Special Preparations	once/man/7 days		120	
Selected Analyses	once/man/day		200	

*To Be Determined

g. Finally, the entire list was iterated, see Table 6.2-2, particularly with respect to repetition rates and the requirements for two-man operation, i.e., a subject and an experimenter. Total experiment times were compared with total crew time availability as influenced by vehicle housekeeping requirements, the continuous Command Module duty requirement and the work-rest cycle. (See Table 6.2-3.)

NOTE

No explicit account was taken of the effects of weightlessness and the adequacy of the restraint system on performance time. Totals, however, have been corrected by a factor of 20% to approximate this effect, based on zero gravity studies in the literature and G.E.'s underwater neutral buoyancy studies.

h. The expendables for each measurement were tabulated including weight and space requirements for each. Reusable items were studied with respect to the number of uses. Quantities of liquid and gaseous expendables, etc., were calculated to provide volumes and weights for storage and resupply assuming a 60-day resupply cycle. (See Table 6.3-2.)

6.2.3 CREW TIME REQUIRED VS AVAILABLE.

The results of the preliminary measurement frequency time requirements study are shown in Table 6.2-1. The resulting measurement time total Table 6.2-3 shows some 896 hours required verse 1269 hours available. Thus the recommended measurement, methods, and frequencies are consistent with the total crew time available for experiment performance on a biomedical/behavioral mission.

6.3 IMBLMS LOGISTICS

6.3.1 RETURN CONSIDERATIONS

It is necessary to return certain laboratory samples, feces, urine, behavioral films, diaries, and log books to earth for further evaluation. Table 6.3-1 lists the volumes and weights of the recommended return items along with the volumes and weights of the carriers. Certain samples must be kept refrigerated, and others must be kept in the freezers at $-20^{o}C$ and at $-70^{o}C$. For these items, the IMBLMS refrigerator and freezers can be removed and used

as the sample carrier. The film, diary and log book can be packaged together in a sealed metal container while the miscellaneous laboratory analysis items including dried feces can be packaged in a separate container.

The return vehicle is the Command Module. GE has reviewed the NASA MSFC Cluster Mission Handbook and ascertained that there is a return sample capability for CSM-1 and CSM-3 of about 250 pounds and about 10 cubic feet each. Since the total returned volume and weight is less than the return capability of the C/M no problem is anticipated in this area. It should be pointed out that Table 6.3-1 notes GE has used the currently allocated areas for the listed experiments of AAP Missions 1-4.

6.3.2 RESUPPLY CONSIDERATIONS

Total IMB LMS consumables for a 60-day mission amounts to 100 pounds and occupies a volume of approximately 3.0 cubic feet. (See Table 6.3-2.) This includes Laboratory Analysis consumables replenishment, film cassettes for recording Behavioral Measurements, and preliminary sample gas replenishment for Physiological Measurements.

The resupply mission is assumed to be a CSM-cargo module, which would be a Saturn IB Launch and consist of a Command Service Module, and an unpressurized cargo module launch mounted in the SLA. The packing of these consumables could be handled by a single 7 cubic foot installation segment, 20 in. x 20 in. x 30 in. with each segment half providing 3.5 cubic feet of storage. This segment would be launch mounted in the cargo module in a fashion similar to the mounting method contemplated for the MDA. Two freezers and the refrigerator would constitute the major part of one-half the segment, and presumably be identical to those brought back on the previous return command module. Furthermore, the returned refrigerator and freezers could possibly be reused. The freezers and refrigerators occupy a volume of approximately 2.5 cubic feet and a weight total of 23.3 pounds.

Approximately 1 cubic foot of the laboratory analysis consumables would be mounted in the freezers and refrigerator. The behavioral measurement film cassettes the physiological consumables and the remaining laboratory analysis consumables, a total of 2.0 cubic feet would be packaged in the second half of the installation segment.

Additionally, there would be about 2.5 cubic foot volume potentially available for other new IMBLMS measurement equipment. The total weight of IMBLMS resupply, included the installation segment structure weight would be about 138 pounds.

Table 6.2-2. Preliminary Integrated Measurement/Frequency/Performance Time Estimates (Including Subject-Experimenter Breakdown)

Measurement Combinations	Preliminary Frequency	Total No. Trials/ Mission	Preliminary Measurement Performance Time (Min)		Total Time Per Mission (Min)			
					One Man		Three Men	
			Subject	Experimenter	Subject	Experimenter	Subject	Experimenter
PHYSIOLOGICAL								
Cardiovascular & Respiratory Measurements (VCG, Arterial Blood Pressure, AAG, Phonocardiogram, Breath-by-Breath Analysis, Respiration Rate)	once/man/10 days	6						
Three Modes								
a. Exercise (Ergometer)			70	70	420	420	1260	1260
b. Prescribed task without pressure suit			90	90	540	540	1620	1620
c. Prescribed task with pressure suit			140	140	840	840	2520	2520
Cardiovascular & Respiratory Measurements (O_2 Consumption, Ventilation, Diffusion, Perfusion, and Cardiac Output)	once/man/10 days	6	30	N/A	180	N/A	1540	N/A
Cardiovascular								
Blood Flow - Doppler (Thoracic Blood Flow, Regional Blood Flow, and Arterial Pulse Contour and Peripheral Venous Pressure)	once/man/5 days	11	20	N/A	275	N/A	825	N/A
Cardiovascular								
(Arterial Blood Pressure)	twice/man/day	106	6	N/A	636	N/A	1908	N/A
Cardiovascular								
(Heart Rate, blood pressure, leg volumes plus oral temperature) LBNP with and without leotards	once/man/5 days	11	85	85	935	935	2805	2805
Respiratory								
(Pressure, volume, and flow and lung volume)	once/man/10 days	6	15	N/A	90	N/A	270	N/A
Metabolic								
Muscle Size and Strength and EMG)	once/man/10 days	6	35	35	210	210	630	630
Core Temperature	once/man/10 days	6	N/A (Performed with other measurements using ergometer					
Metabolic/Nutritional (Caloric Intake)	Whenever nourishment is taken	Variable	N/A To be considered part of time allocated for meals	N/A				
Metabolic/Nutritional (Body Mass)	once/man/day	53	11	N/A	583	N/A	1749	N/A

Table 6.2-2. Preliminary Integrated Measurement/Frequency/Performance Time Estimates (Including Subject-Experimenter Breakdown) (Cont)

Measurement Combinations	Preliminary Frequency	Total No. Trials/ Mission	Preliminary Measurement Performance Time (Min)		Total Time Per Mission (Min)			
					One Man		Three Men	
			Subject	Experimenter	Subject	Experimenter	Subject	Experimenter
NEUROLOGICAL	once/man/10 days	6						
Angular Acceleration Threshold			5	5	30	30	90	90
Oculogyral Illusion			5	5	30	30	90	90
Ocular Counter Rolling			5	5	30	30	90	90
Visual Task with Head Rotation			10	10	60	60	60	60
Agravic Perception			10	10	60	60	60	60
Electroencephalogram			5*	5	30	30	30	30
Electronystagmogram			5	5	30	30	30	30
BEHAVIORAL								
Sensory Test Battery								
Visual	once/man/10 days	6	60	N/A	360	N/A	1080	N/A
(Acuity, Depth perception, Phorias, Color, Absolute Brightness thresholds, Adaptation)								
Auditory	once/man/10 days	6	30	N/A	180	N/A	540	N/A
(Pitch Discrimenation and absolute intensity thresholds)								
Kinesthetic Function	once/man/10 days	6	55	55	330	330	990	990
(Propioception, cutaneous)								
Learned Activity	once/man/10 days	6	22	N/A	132	N/A	396	N/A
Reaction time (auditory and visual								
Tracking (Pursuit and compensatory)	once/man/10 days	6	20	N/A	120	N/A	360	N/A
Vigilance								
(Blink rate - attention)	once/man/10 days	6	120	N/A	730	N/A	2160	N/A
Higher Thought Processes (Arithmetic, Analogies, Problem Solving)	once/man/10 days	6	24	N/A	144	N/A	432	N/A
Memory (Long and short term)	once/man/10 days	6	24	N/A	144	N/A	432	N/A
Time and Motion Study (CM, OWS, Airlocks, EVA)	once/man/10 days	6	30	30	180	150	540	540
Clinical Evaluation (Intercrew Communications, Tests, Data from other measurement)	once/man/day	53	5**	N/A	265	N/A	795	N/A
LABORATORY ANALYSIS								
Blood (Drawing for Preservation)	once/man/day	53	10	65 ①	530	N/A	1590	3445
Urine (Collection & Storage)	once/man/day	53	N/A	40 ①	N/A	N/A	N/A	2120
FECES (microbiological sampling and electrolytes)	once/man/7 days	8	N/A	60 ①	N/A	N/A	N/A	480
FECES (dried mass)	once/man/day	53	N/A	15 ①	N/A	N/A	N/A	795
SWEAT (Collection & Storage)	once/man/7 days	8	120	30 ②	960③	240	2880③	720
Microbiological and Immunnological Sampling (Excluding Feces)	once/man/7 days	8	N/A	180 ①	N/A	N/A	N/A	1440
Special Preparations (e.g. Karyotyping)	once/man/7 days	8	N/A	120 ①	N/A	N/A	N/A	960

① Experimenters time for total samples
② Experimenters time for each subject
③ Only 5% of time used for time line as subject can participate in another measurement.

*Preparation Time Only - Recording will be accomplished during performance of other tasks, i.e., sleeping, behavioral experiments, etc.
**Time for tests only - other data will be from measurements in other areas.

Table 6.2-3. Preliminary IMBLMS Measurement Integration Time Requirements vs Measurement Time Available

Integrated Measures	Preliminary Time In Hours For Three Men		
	Total	Subject	Experimenter
Physiological	397.7	243.0	154.7
Behavioral	154.2	128.7	25.5
Laboratory Analyses	194.9	28.9	166.0
Totals	746.8 + 20% = 896.2	400.6	346.2

Time Available = 1269 Hours

Time Required = 896.2 Hours

Surplus Times may be allocated for:

a. Unscheduled maintenance

b. Increasing repetitions for selected measurements

c. Operational time requirements i.e., EVA-Resupply-etc.

d. Errors in time estimates

e. Dividing sleeping and CM activities to degree possible

Table 6.3-1. Return Capability

Subsystem	Item	Return Item			Return Carrier			Total Return Weight (lb)	Special Handling
		Name	Weight (lb)	Volume (ft^3)	Name	Weight (lb)	Volume (ft^3)		
Laboratory Analysis	1	Control Temperature Samples	18	0.21	Refrigerator ⑤	4.5	0.33 ①	22.5	Vehicle Electric Power for Freezer
	2	-20°C Samples	24.4	0.35	Freezer No. 1 ⑤	9.4	1.10 ②	33.8	Vehicle Electric Power for Freezer
	3	-20°C Samples	24.4	0.35	Freezer No. 2 ⑤	9.4	1.10 ③	34.4	Same
	4	-70°C Samples	0.6	0.01	-70° Section of Freezer No.2 ⑤	-	-	-	-
	5	Film and Dried Feces	20.5	0.6	Separate Container ⑤	1.0	1.00 ④	27.5	Sealed Container. Cabin Ambient
Behavioral	6	Film Cassettes Diary Data Log	6	0.06		⑤			
		Totals	93.93	1.58		Totals	3.53	118.2	

Notes:

① Return Space Available Experiment M056, 0.3 ft^3 (6 in. x 8 in. x 10 in.)

② Return Space Available Experiment D016, 1.0 ft^3 (18 in. x 12 in. x 8 in.)

③ Return Space Available Experiment S055, 2.0 ft^3 (10 in. x 10 in. x 35 in.)

④ Return Space Available Experiment M052, 1.0 ft^3 (15 in. x 18 in. x 3 in.)

⑤ Container Weights Include Samples

(Reference Cluster Mission Data Book NASA MSFC)

Table 6.3-2. Resupply Consumables

Consumables	Weight (Lb)	Volume (Ft^3)
Laboratory Analysis *	86	2.4
Film Sampling Equipment Sample Containers Reagents		
Behavioral Measurement	6	0.3
Film Cassettes Diary Data Log		
Physiological Measurement	8	0.3
Electrodes Skin Preparation Sample Gas Containers		
	100	3.0

* See Section 4.0 (Volume II) for detail breakdown of Laboratory Analysis consumables.